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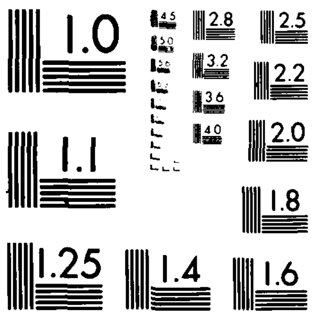


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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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# DESIGN CALCULATION PROCEDURE FOR PASSIVE SOLAR HOUSES AT NAVY INSTALLATIONS IN REGIONS WITH WARM, HUMID CLIMATE -- VOLUME III

October 1981



An Investigation Conducted by
New Mexico State University
Las Cruces, New Mexico

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These reports present design calculation procedures for passive solar houses. A "worksheet" approach is used in that the user may work through an example passive solar design by following the text in the report. Included are tables for heating degree days, solar heat gains, building R factors, orientation factors, roof overhang designs, etc. Performance is

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) calculated on a monthly basis. The reports are presented for five (5) geographical regions with content and text format similar, differing only in the appropriate regional factors. This volume gives appropriate designs for Navy installations in regions with warm, humid climate.

ACKNOWLEDGEMENT

This design calculation procedure was originally developed for the State of New Mexico under a research project funded by the New Mexico Energy and Minerals Department (Grant #78-2228, Monika Lumsdaine, Principal Investigator) and published as Report NMEI 22-SA by the New Mexico Energy Institute at New Mexico State University. It has been tested and used extensively in workshops sponsored by the New Mexico Solar Energy Institute at NMSU. Navy Contract #N62583/79M R585 was awarded to the NMSEI to adapt the procedure with supporting information for use in other geographical locations in the United States, particularly in regions with Navy installations. Marilyn A. Chase, Mechanical Engineering student (NMSEI), has assisted in assembling data and reducing it to graphical form. She has also developed the design example for warm, humid climate. Ed Durlak, Naval Civil Engineering Laboratory, Port Hueneme, California, has carefully reviewed the draft of this manual and made many suggestions to make the procedure easier to apply by Navy personnel.

M.L.

E.L.

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# 1. INTRODUCTION

The simple design method presented here has been developed in response to the following needs and objectives:

(a) This calculation procedure can be used by designers, contractors, and owner/builders working on plans for passive solar houses. The method is simple enough for people to apply who do not have an extensive background in science, engineering or mathematics. All necessary supporting data is provided.

(b) The procedure can be used to evaluate the performance of various retrofit design options.

(c) Design calculations for DOE and HUD solar projects are quite complicated. The procedure provides a "primer" to familiarize interested people without previous experience with the basic steps involved in heat load calculations for solar applications.

(d) Building inspectors, FHA, and other financial institutions may require heat load calculations, especially if the planned building does not include a full-size backup heating system.

(e) The design calculation procedure also provides a uniform format for reporting and evaluating the performance of existing passive solar homes in comparison studies.

Since different climates call for somewhat different approaches to passive solar design, five different variations of the original manual have been prepared:

Vol. I - COLD CLIMATE (includes Aleutian Islands, Alaska, the New England Coast from New Haven, Connecticut to Brunswick, Maine, and the southern Great Lakes region around Chicago, Detroit and Cleveland).

Vol. II - TEMPERATE EAST COAST CLIMATE (includes the northern Philadelphia - Washington region and the Atlantic Coast from Norfolk to Charleston).

Vol. III - WARM, HUMID CLIMATE (includes Florida, Hawaii, and the Gulf Coast).

Vol. IV - PACIFIC NORTHWEST CLIMATE (includes only areas west of the Cascades from Seattle, Washington, to Portland, Oregon).

Vol. V - WARM CALIFORNIA CLIMATE (includes the coast from Oakland to San Diego as well as high and low desert areas).

It is assumed that the designer has a basic knowledge of passive solar mechanisms and their operational characteristics. A brief summary is given in the following chapter, and a number of useful reference books are listed at the end of this manual.

The calculation procedure is divided into several steps with corresponding worksheets and supporting data. An additional blank set of worksheets easily removable for xeroxing is attached.

This simple procedure should be especially helpful during the early design phase to evaluate the effect of various design options and combinations and again in checking out the final design, and to determine the approximate auxiliary heat load. The procedure is best applied to direct gain, Trombe walls (mass or water), solar roofs and combinations of these. Sunspaces that are an integral part of the house fall under direct gain; attached solar greenhouses with a large amount of exposed surfaces require an additional set of calculations for the greenhouse alone, with the net heat gain then added to the house calculations. Using a simple hand calculator or slide rule will save time.

Although a brief discussion of passive cooling methods is given, the calculation method does not include a procedure to determine actual energy savings due to passive cooling.

## 2. REVIEW OF DEFINITIONS

Solar systems for heating (and cooling) can be divided into two basic categories: active (mechanical) systems and passive (natural) systems. Active systems need some energy input outside of solar to operate. This so-called "parasitic" power requirement can, in some applications, be so large that none or very little net savings will result by using the active solar system. This is true, for instance, in smaller intallations of lithium-bromide absorption solar cooling. Active systems resemble in their application conventional HVAC systems in that they consist of a number of components that can be installed after the structure has already been erected. Passive (natural) systems operate without mechanical components or parasitic power input by making use of the natural laws of heat transfer and the properties of building materials to store or transmit solar energy to such an extent that the entire building becomes a live-in solar collector. Thus, passive systems are built right into the structure. The completed building and passive solar system(s) are quite easy to operate since many controls are daily or seasonally automatic. The passive system(s) must be designed and calculated carefully for satisfactory performance, because mistakes will be very difficult to correct once they are built into the house. On the other hand, many options exist that make the design quite flexible, and some features do not have to be fixed until the house has been lived in for a year or so---the building has to be fine-tuned, so to speak. The performance of a passive system can be augmented with the addition of blowers or fans to obtain better heat distribution. Technically speaking, passive systems that use mechanical energy to transport heat around are known as hybrid systems.

Table 2.1 lists definitions for common heat transfer terms used in this manual. The primary passive solar heating methods are direct gain, thermal storage wall (Trombe or water wall), and sunspace (greenhouse); roof ponds, thermosyphon systems and hybrid solar roofs involve more hardware and are thus somewhat more complicated. The heat transfer mechanisms involved between the sun, the living space and the storage mass are very subtle and closely interrelated; thus the building must be designed carefully, and the interaction between the passive solar system(s) and the people living there must also be considered.

TABLE 2.1

Definition of Heat Transfer Terms

HEAT is the sum of the kinetic energy of all molecules in a mass of material due to the random molecular jostling motion.

TEMPERATURE is the intensity of heat (or molecular velocity) and does not depend on the amount of mass present.

CONDUCTION is heat moving from a warmer to a colder region in the same substance; this type of heat transfer takes a definite amount of time and depends on the conductivity of the material. ⟹

CONDUCTIVITY is a measure of the rate at which heat is conducted through a slab of material whose two sides are kept at a constant temperature differential.

CONVECTION is the circulatory motion of a fluid (liquid or gas) caused by temperature differences without the use of mechanical devices. Heat transfer by convection also takes a certain amount of time. It is sometimes called natural convection to distinguish it from forced convection.

FORCED CONVECTION occurs when air or liquids are made to circulate with the aid of fans/blowers or pumps.

RADIATION is the transfer of heat by electromagnetic waves from an emitter at higher temperature to an absorber at lower temperature. Conversion from radiation to heat occurs when the radiation is absorbed by a substance. This heat transfer occurs practically instantaneously. The radiation properties (emissivity and absorptivity) and temperatures of the emitting and absorbing surfaces will determine the rate of heat exchange between them.

SENSIBLE HEAT is the heat involved when the temperature of a storage material is raised or lowered.

LATENT HEAT OF FUSION is the heat involved in changing a substance between the solid and liquid states.

SPECIFIC HEAT is the quantity of Btu's which can be stored in a material per pound and per degree Fahrenheit.

HEAT CAPACITY is the quantity of heat that can be stored in a cubic foot of material; it is the specific heat of the substance multiplied by its density.

CONTINUED

Table 2.1 Continued

RADIANT INTENSITY depends on the size and temperature of the emitting surface and the proximity of the absorber.

REFLECTIVITY is a property of materials to "bounce-off" radiant energy instead of absorbing it.

ABSORPTION is the phenomenon of conversion of electromagnetic waves of radiated energy to heat by the surface of a material. From the surface, the heat is then transferred into the material by conduction.

TRANSMISSIVITY is the property of certain materials to let radiant energy pass through without absorbing all of it.

THERMOSYPHONING is a term traditionally applied to mechanical systems that use the natural rise of heated gases or liquids for heat transport.

AUXILIARY SYSTEM is the backup system or conventional space heating or water heating system used to supply energy during periods of completely cloudy weather when the solar systems cannot supply all the energy demanded.

INSULATORS are materials with a low conductivity. These materials are said to have a high resistance to heat flow by conduction and are identified by a high R-value.

1 Btu (BRITISH THERMAL UNIT) is the heat necessary to raise one pound of water by one degree Fahrenheit.

LIVING SPACE as defined and used in this manual denotes any space in the house occupied by people for a variety of activities such as cooking, heating, sleeping, bathing, play and recreation, etc.

U-VALUE (or the coefficient of heat transmission of a material or combination of materials) is defined as the rate of heat flow per square foot per degree Fahrenheit temperature between air on the inside and air on the outside of a wall, roof or floor. It is the reciprocal of R, the thermal resistance of a material. Note that R-factors can be added, whereas U cannot. To calculate the U-value of a combination of substances, first find the total R-value by adding the individual R factors, or $R_1 + R_2 + R_3 + \ldots = R_{Total}$ then $U = \frac{1}{R_{Total}}$.

The main heat transfer mechanisms involved during the day and night for the different types of passive solar heating systems are briefly discussed in Sections 2.1 through 2.4; a summary of passive cooling is given in Section 2.5.

## 2.1 Direct Gain

The simplest and most widely used passive solar heating system is direct gain. It consists of large, south-facing windows combined with a heat storage mass in the room. If the system incorporates operable windows and movable shading and window insulation, a variety of ways to control the level of comfort, both during summer and winter, are provided. The daily temperature fluctuations in the living space are somewhat higher than for a Trombe wall system, and glare may be a problem under certain circumstances. The solar greenhouse is also an application of the direct-gain method; here the daily temperature fluctuations are quite large because glazing is increased and storage mass is relatively small in order to yield excess heat for transfer into the living space adjacent to the greenhouse. Maximum room depth for effective direct gain is 2½ times window height (from floor level) [1]. This will also give good daylighting. The basic schematic is shown in Figure 2.1.

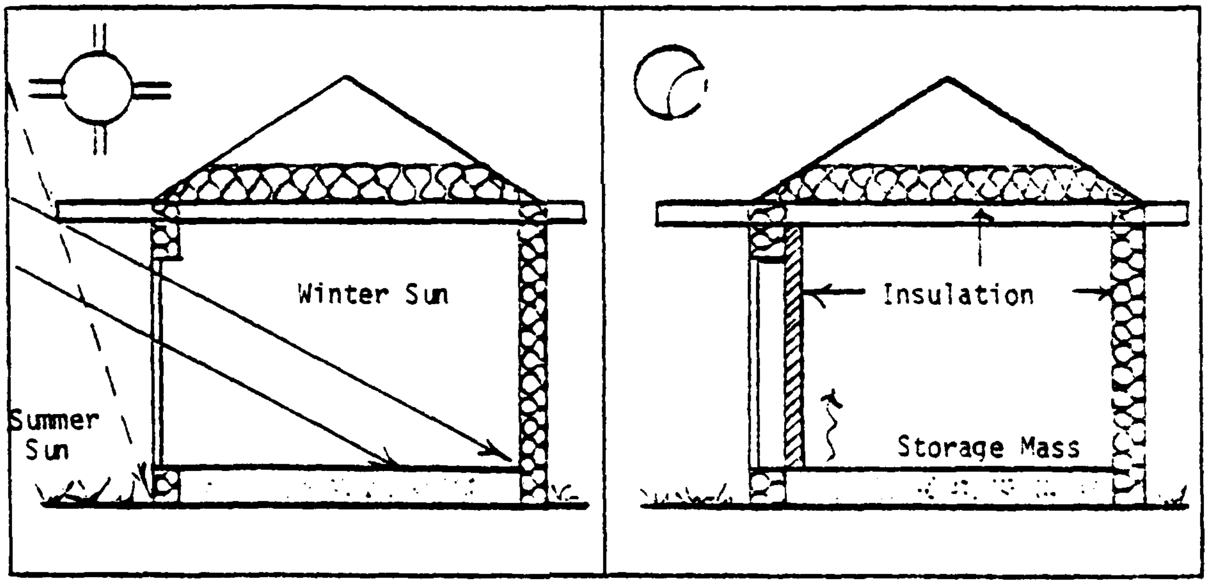



Figure 2.1 Schematic of the Basic Direct Gain Passive Solar Heating System (Winter Operation)

A great degree of freedom exists in the placement of the storage mass in direct-gain systems, as shown in Figure 2.2. The storage mass can be heated either by sunlight striking it directly (preferably a considerable portion of a winter day), or by solar-heated air passing over it, or by reflected radiation from other surfaces in the room. If the storage surface is struck directly by

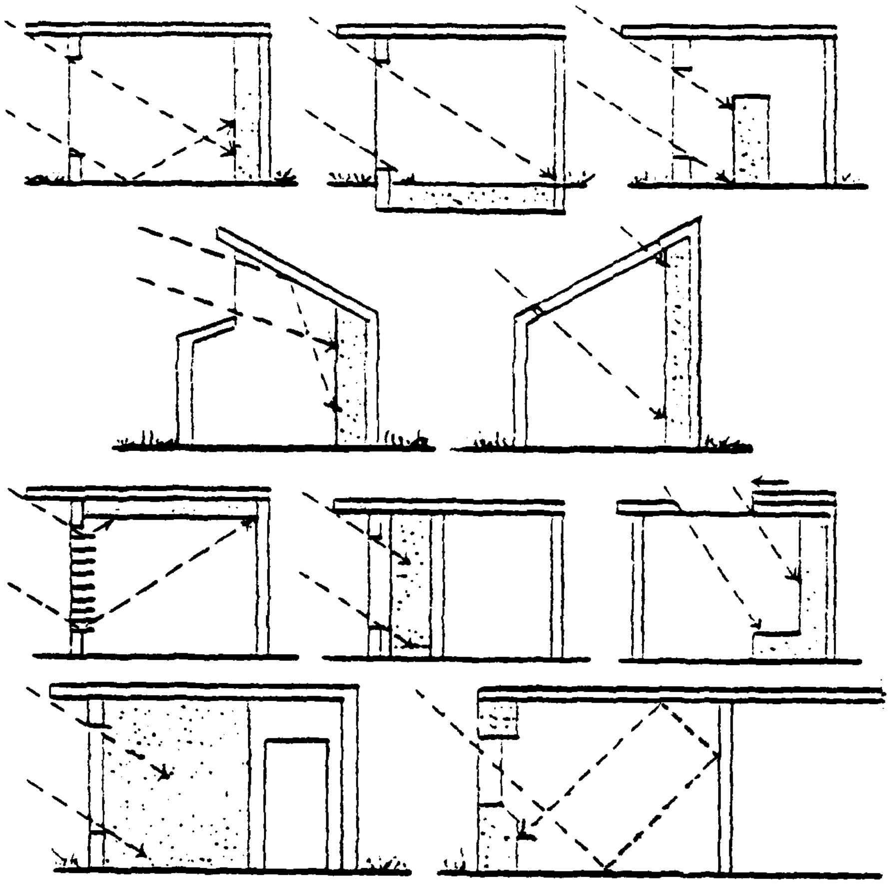


Figure 2.2 Examples of Direct-Gain Window and Storage Locations

sunlight, its performance is increased if its color is dark (see Table 2.2). If the mass only absorbs radiation bounced off from other surfaces, the color does not matter, but the volume required is about 4 times larger than if it received sun all day long in order to achieve similar comfort conditions.* When room temperature falls below that of the storage mass, the storage will begin to reradiate this energy. Some heat transfer also takes place through barely noticeable convective air currents. Attention must be paid to provide sufficient surface area for efficient storage. The amount of storage also

*For example, if storage mass in the sun increases by 20° F from morning to mid-afternoon, air temperature in the room will rise by about 10° F. For a 10° F air temperature rise, storage mass not receiving direct solar radiation will increase by only 5° F; thus the volume to store an equivalent quantity of heat must be 4 times larger.

depends on the climate. In areas with much winter sun, sufficient mass to store heat over 2-3 days is a good idea. This is also true for places that experience large night-day temperature fluctuations in the summer. Places with cloudy winters and/or humid summers should have storage sufficient only to heat the home through one night.

TABLE 2.2
Absorptivity of Building Materials and Paints

| Material/Color | Absorptivity |
|---|---|
| Slate Composition Roofing | 0.9 |
| Graphite | 0.84 |
| Red-Brown Linoleum | 0.84 |
| Asbestos Slate | 0.81 |
| Dark Colors | 0.8 |
| Gray Soft Rubber | 0.65 |
| Concrete | 0.59 |
| Red Brick | 0.55 |
| Medium Colors | 0.5 |
| Cork | 0.45 |
| Light Colors | 0.2 |
| Aluminum Paint | 0.18 |
| White Tile | 0.18 |
| Anodized Aluminum | 0.15 |
| Wood, Paper, Cloth, Gypsum | 0.1 - 0.45 |

The principal storage materials are water or different kinds of masonry: adobe, brick, sand or cement-filled concrete block (slump block or cinder block), poured concrete, rammed earth, stone, rock, or tile. The heat transfer and storage characteristics of masonry materials do not vary by much; therefore, the choice can be based on local availability, cost, structural considerations and local building code requirements. For storage over several days, masonry is more effective than water. Because of internal convection, water storage containers release heat more quickly than do 2 ft thick masonry walls, for example. From a construction standpoint, it is also easier to incorporate larger amounts of masonry storage than oversize water containers. But because water requires only about 1/3 the volume of masonry to store an equal quantity of heat, water may be preferable in retrofit applications (if existing construction is able to support this load). Table 2.3 lists a number of possible water containers for passive solar heat storage.

TABLE 2.3
Water Containers for Passive Solar Heat Storage
(From D. A. Bainbridge, "How to Build a Water Wall," SOLAR AGE, Vol. 4, No. 8, Aug. 1979, pp. 38-41).

| TYPE | SOURCE | SIZE | VOLUME | COST/GAL. | INSTALLED COST | NOTES |
|---|---|---|---|---|---|---|
| Tanks* | Local welder | Any (1-1/2x3x6 3x6 ft recom.) | Any | 30¢ to $1.50 | 50¢ to $1.50 | Aesthetically appealing, easy to install, effective. |
| Drums* | Drum manufacturer, chemical supply, etc. | | 30 or 50 gal. | 10 to 45¢ | 20¢ to $1.50 | Cheap, readily available, hard to clean, must be stacked carefully. |
| Culverts* | Pipe supply, scrap yards | 12 in. + diam. | Depends on length | 30 to 50¢ | 50¢ to $1.50 | Tough, attractive to some, help where floor space is tight. Make sure installation is seismically safe. |
| Kalwall Cylinders | Kalwall | 12 in. & 18 in. | Depends on length | 40¢ to $1.45 | 50¢ to $1.75 | Translucent, easy to install and move, easy to damage. Best where traffic is light. |
| PVC Pipes | Agricultural supply | 6 in. & 12 in. | Varies | 10 to 20¢ | 30¢ to $1.20 | Light, durable, heat transfer not as good. Must rack or brace to mount. |
| Glass Bottles | Various | Varies | Up to 10 gal. | | | Cheap, readily available, must seal carefully, moving difficult. |
| Steel or Aluminum Pipes* | Scrap yard or supply | 6 to 12 in. | Varies | 10 to 40¢ | 30¢ to $1.50 | Readily available, time-consuming to build racks, hard to clean. |
| Modules | One Design | Steel or fiberglass | | $1.00/gal. est. | $1.50/gal. | Easy to install and ship. Good potential for cooling. |
| Tanks* or Modules | Tabline | 46 in. x 4 ft x 16 in. | 90 gal. | $1.00+/gal. est. | $1.50/gal. | Easy to retrofit, good interface with stud construction. |

* May required corrosion inhibitor. Also cap and container should be of the same material to prevent leaks.

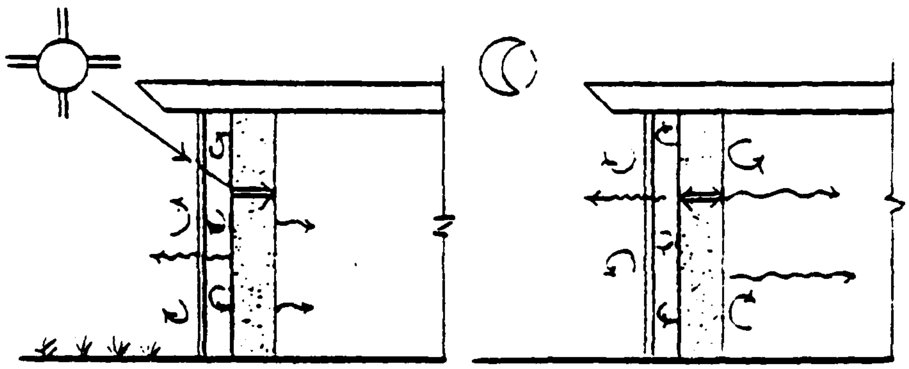
## 2.2 Thermal Storage Walls

The thermal storage wall, since it is located between the sun and the living space, is an indirect passive solar heating system. The three main types of thermal storage walls (vented and unvented Trombe wall and water wall) are combined collector/storage passive heating methods and have somewhat different performance characteristics since the heat transfer mechanisms for each type vary, as indicated on Figure 2.3. Additionally, performance is also influenced by wall thickness, the conductivity of the material, and insulation. It is highly recommended that double glazing (two sheets of glass or plastic) be used to reduce heat losses from the storage wall to the outside unless night insulation is provided. The wall surface facing the sun is painted dark (though not necessarily black) to increase absorption.

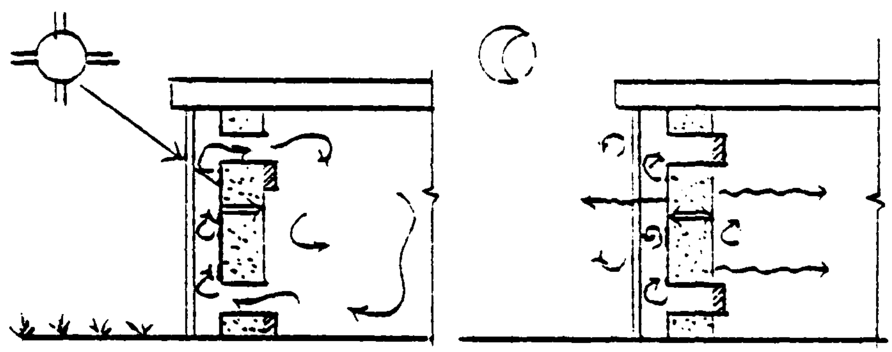
Rooms heated with thermal storage walls should not be more than 20 feet deep [1]. Masonry has the advantage of providing a structural function (load-bearing wall); water, on the other hand, requires less volume. The Passive Solar Energy Book by Edward Mazria, Rodale Press, Emmaus, Pennsylvania, 1979, and the Thermal Storage Wall Design Manual by Alex Wilson, New Mexico Solar Energy Association, P. O. Box 2004, Santa Fe, NM 87501 ($4.75) give much information on the thermal storage wall, including sizing and construction details.

## 2.3 Sunspace (Solar Greenhouse)

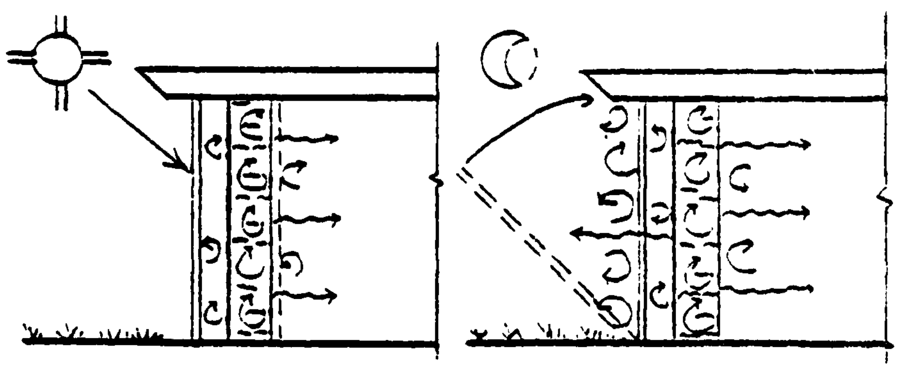
The sunspace (solarium or greenhouse) system is a combination of direct gain and Trombe wall, as shown in Figure 2.4. The storage mass in a greenhouse is sized to keep the plants from freezing during cold winter nights. The daily air temperature swing in the greenhouse can be as much as 40°F, with the excessive heat available for heating the living spaces adjacent to the greenhouse. In warmer climates, sufficient and correctly placed vents must be provided to prevent overheating in the summer. Figure 2.5 shows the schematic of a northside greenhouse retrofit possible for warmer climates. A south greenhouse retrofit is suitable even in cooler climates (if night insulation for the glazing is provided).



(a) UNVENTED TROMBE WALL with roof overhang for warm climate (ideal for retrofit to masonry buildings).



(b) VENTED (THERMOCIRCULATION) TROMBE WALL for colder climate and increased efficiency.



(c) WATER WALL with movable interior and exterior insulation for heat transfer control and increased efficiency. (Efficiency also depends on container surface material.)

Figure 2.3 Heat Transfer Mechanisms of Thermal Storage Walls

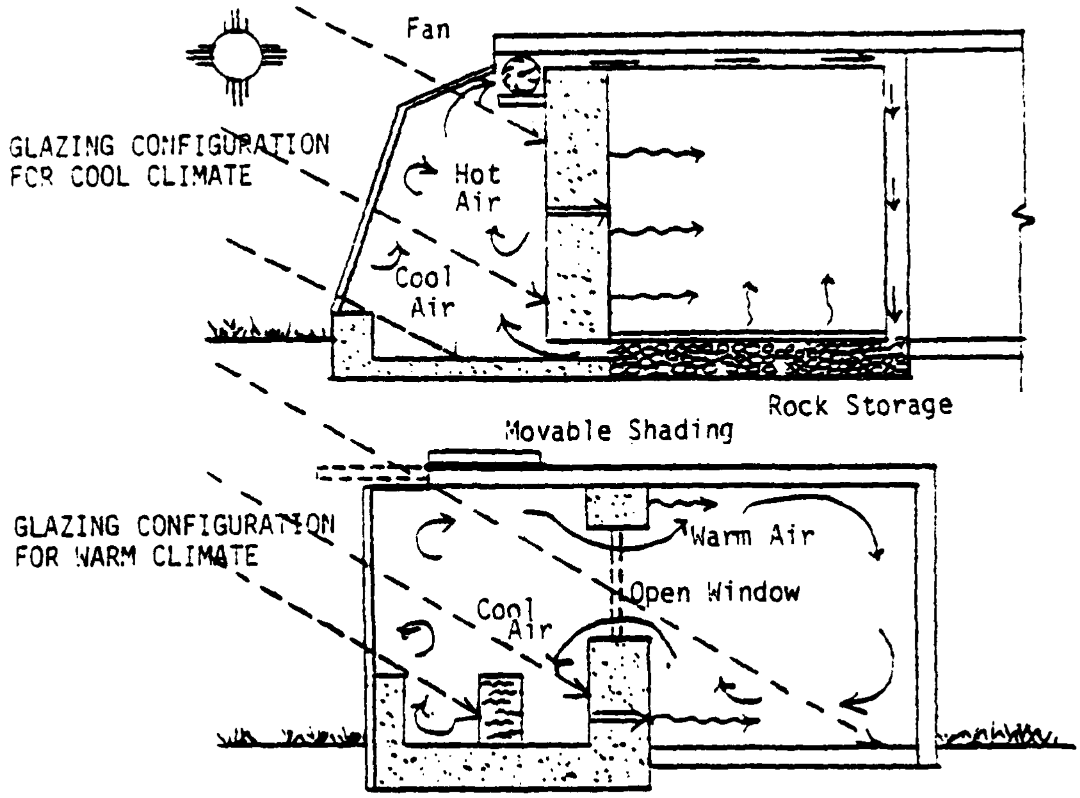



Figure 2.4 Heating of Living Space with Solar Greenhouse

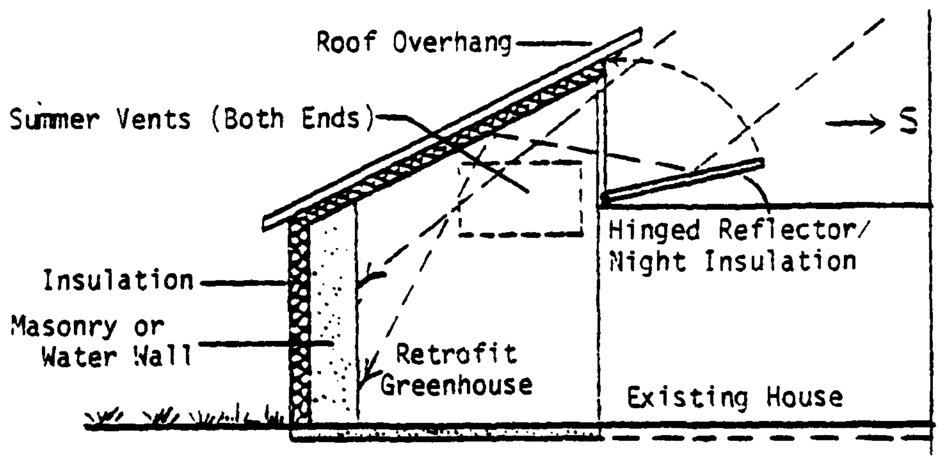



Figure 2.5 Schematic of North-Side Greenhouse Retrofit

## 2.4 Other Passive/Hybrid Systems

A number of other passive/hybrid systems have been developed for residential applications. These are somewhat more complicated to design and build by contractors without previous experience, or they are applicable to limited climatic regions for best performance. Among these systems are the roof pond developed by Harold Hay for Southern California, the hybrid solar roof (Southern New Mexico) and the natural convective loop system (thermosyphon) which more closely resembles an active solar system since it employs a bank of solar collectors. Schematics of these systems are shown in Figures 2.6, 2.7, 2.8 and 2.9.

Much research and development work is currently underway with new heat storage materials. In the passive methods described above, the usual heat storage medium is either masonry or water (or sometimes a combination of both); these media store sensible heat by undergoing an increase in temperature. Phase-change materials, on the other hand, make use of latent heat of fusion to store large quantities of heat without much temperature fluctuation. Experimental units of phase-change materials have been able to store and yield up to twenty-five times more heat than rock beds of equal mass under the same operating conditions [2]. A suitable phase-change material must have the following characteristics: the melting/freezing point must be at a convenient temperature, it must be nontoxic, nonflammable, noncorrosive and otherwise acceptable to building codes, it must perform reliably and without loss in efficiency over a long life cycle, and it should be inexpensive, widely available and of nonfossil fuel origin. So far, only a group of salt hydrates developed by Dr. Maria Telkes come close to meeting a number of these requirements. Sodium sulphate decahydrate (Glauber's salt) and sodium thiosulfate pentahydrate have been used in experimental solar houses. The major problems found have been supercooling, segregation of the components of the mixture after a few cycles, and failure of the containers. Certain plastics are being investigated for containers; another approach using foamed concrete block impregnated with eutectic salts and sealed with a membrane also shows promise [2].

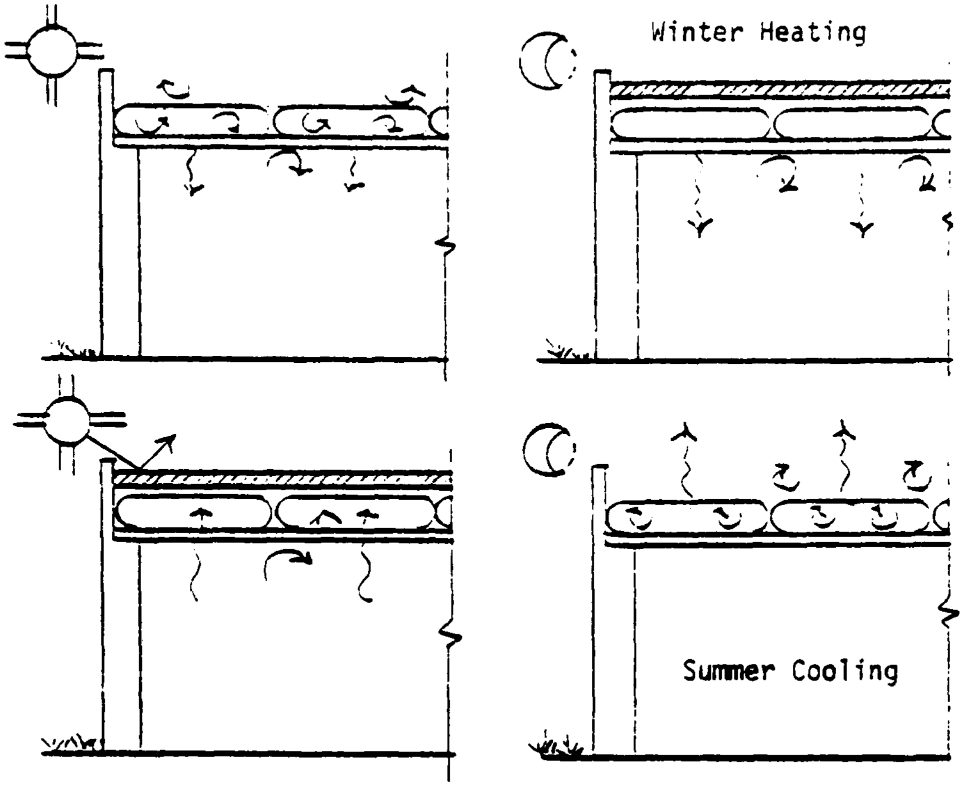



Figure 2.6 The Roof Pond in Warm Climate

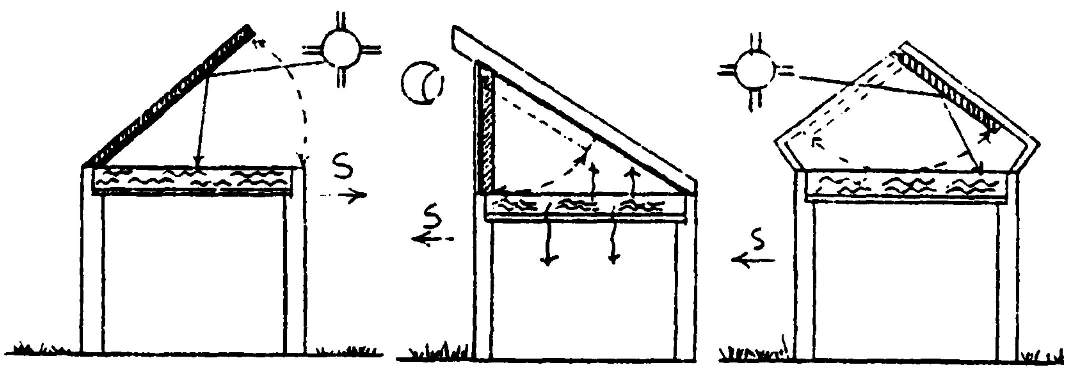



Figure 2.7 Thermal Roof Options in Colder Climates with Combined Reflector/ Night Insulation

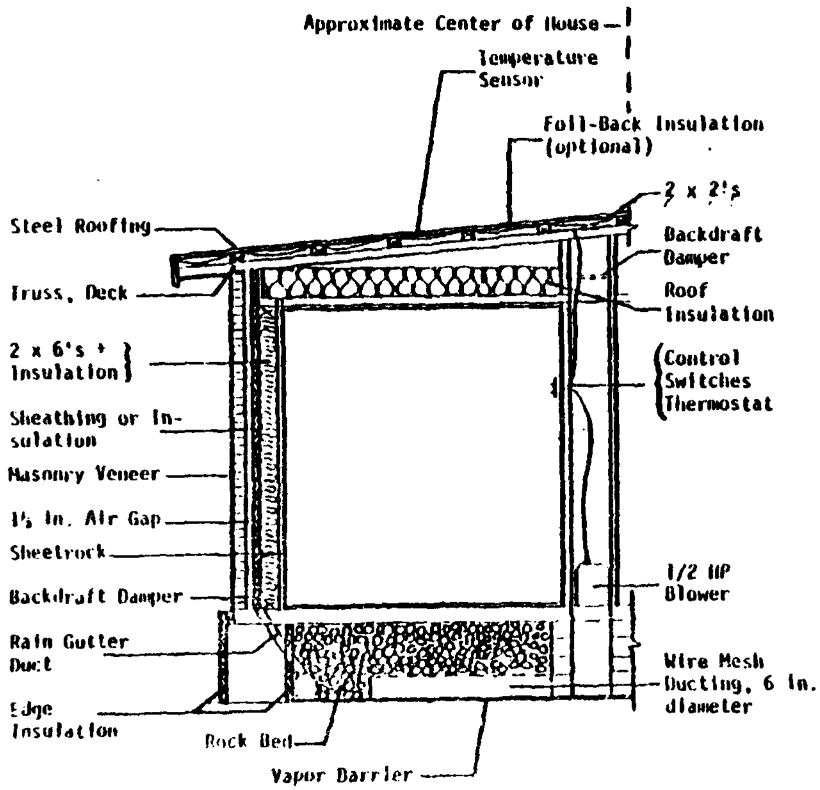
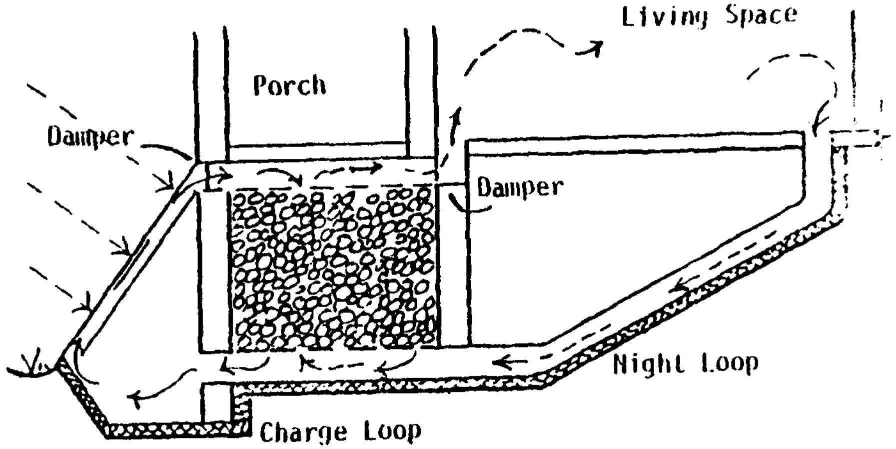
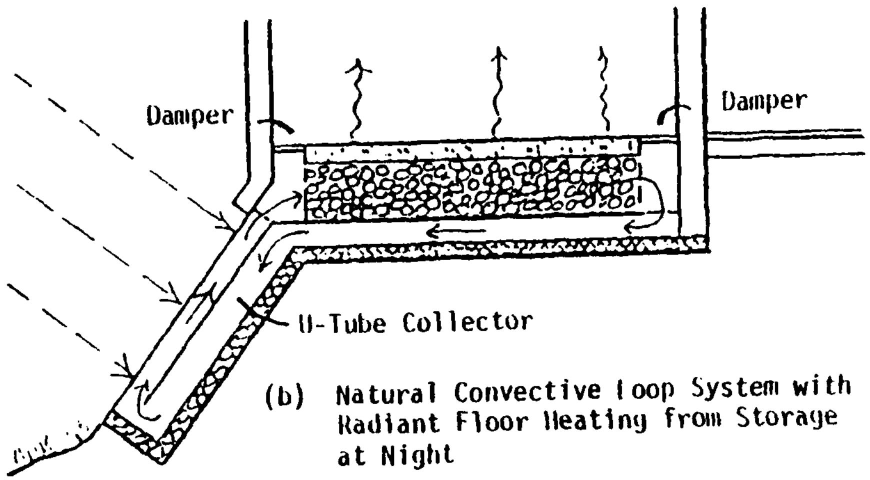



Figure 2.8 Schematic of Solar Roof System (Steel Roof, Masonry Veneer Version). The system can also be used with shingled gable roofs and stucco or siding.




(a) Double Natural Convection Loop System




(b) Natural Convective Loop System with Radiant Floor Heating from Storage at Night

Figure 2.9 Schematics of Natural Convective Loop Systems with Alternate Storage Location and Function.

## 2.5 Passive (Natural) Cooling

A number of techniques are possible for space cooling. Some are very energy-intensive such as refrigerated air conditioning or the lithium-bromide active solar cooling system. Others employ only a fan or blower (forced ventilation, evaporative cooling). Shading, natural ventilation and earth cooling by induced convection are methods which require no parasitic power input. In hot, dry climates, shading, natural and induced ventilation, evaporative cooling, night-sky radiation (i.e. roof ponds), time-lag cooling and earth cooling can be used. Hot-humid climates pose a more difficult problem for natural cooling, since only shading, ventilation and earth cooling will work here. Dehumidification will decrease relative humidity to more comfortable levels but will increase air temperature [5].

Shading: One of the easiest ways to reduce summer heat gain is by shading windows (and walls as well as roofs where little insulation is used). However, sufficient indirect light should be allowed into the building to avoid turning on electric lights during the day. Overhangs, shades or louvers outside the building work better than interior shutters because they block the heat before it enters the house. Deciduous trees and vines are ideal for shading roofs, east and west walls as well as the grounds next to the entire building. Paved areas especially should receive shading after 10 a.m. in the summer.

Natural Ventilation: This method can be used in locations that have sufficient and fairly dependable summer breezes. It must not be used during times when outdoor temperatures are much higher than indoor temperatures, especially in buildings with interior heat storage mass. During such times, ceiling fans or other types of portable fans can be used to locally increase comfort inside the house.

If winds are not sufficient, ventilation can be induced with the chimney effect. This method makes use of the natural property of heated air to rise. If a solar greenhouse is vented at its highest point while being coupled to the house with low intake vents, hot air can be drawn out of the house. Special monitors can be built on the roof to accomplish the same purpose.

Attic fans or turbolators can be used to reduce heat build-up in the attic space and for drawing fresh outside air into the house.

Time-Lag Cooling: In areas which have large day/night temperature differences, natural ventilation can be combined with a large amount of interior and exterior mass. During the day, such buildings are tightly shut. Many passive solar-heated homes in suitable climates can make effective use of this method for cooling.

Evaporative Cooling: In areas with low humidity, this method is effective but requires a constant supply of water. Various systems and degrees of complexity are available, from the simple "swamp" cooler common in the Southwest to two-stage indirect or regenerative systems employing rockbeds. The open roof pond, indoor fountains and pools are other means of evaporative cooling.

Night-Sky Radiation: In open areas with low humidity, the roof of a building can loose a large amount of heat to the cool night sky through radiation. This principle is employed in roof ponds and with somewhat less efficiency (depending on type) also with the summer mode of the solar roof system.

Earth Cooling: Underground buildings and earth-to-air heat exchangers make use of the cool, constant temperatures that prevail a relatively short distance into the ground. Insulation must be used to prevent too cool temperatures. In humid locations, earth cooling must be combined with an earth-to-air heat exchanger, and the water vapor must be condensed out at the air intake tube before the air is supplied to the house. This method of course can only be used on sites which have a low water table.

## 3. CLIMATE AND PRELIMINARY CONSIDERATIONS

### 3.1 Climate

Passive solar houses must be designed specifically for the climatic conditions at the site. Besides the amount of sunshine available on any day (or the monthly average total), wind direction and velocity, precipitation and the average temperature are also important considerations. Heating degree days are the number of degrees the daily average temperature is below 65°F. A day with an average temperature of 30° has 35 heating degree days, while one with an average of 65°F or higher has none. This data is usually given in monthly and yearly totals and is used to calculate the heating load of the building, since fuel consumption for heating a building is linearly proportional to heating degree days. The data is usually available from the local Chamber of Commerce, or the values given on Table 4.8 may be used if more accurate information is not available locally. However, it must be remembered that "climate is never an average" [3], even though average monthly figures are used in the heat load calculations for convenience.

Local microclimates can also vary considerably from the official data published by the weather stations. Therefore, the data used in the calculation procedure must be adjusted as much as possible for the expected conditions at the building site; on the other hand, because of the large variations that can occur from day to day, month to month and year to year, average values can give a good overall idea of the expected performance of the design under fairly normal conditions. Also, temperature and comfort are not the same, since humidity levels and air movement as well as room surface temperatures (due to radiant heat transfer) have a large influence on human comfort and response to surrounding temperatures, as illustrated in Figure 3.1.

Besides heating degree day data, accurate solar insolation data is important in the performance calculations for passive solar houses. Here again a number of difficulties are present. Solar data is usually in the form of average daily totals of solar radiation on a horizontal surface. However, for most

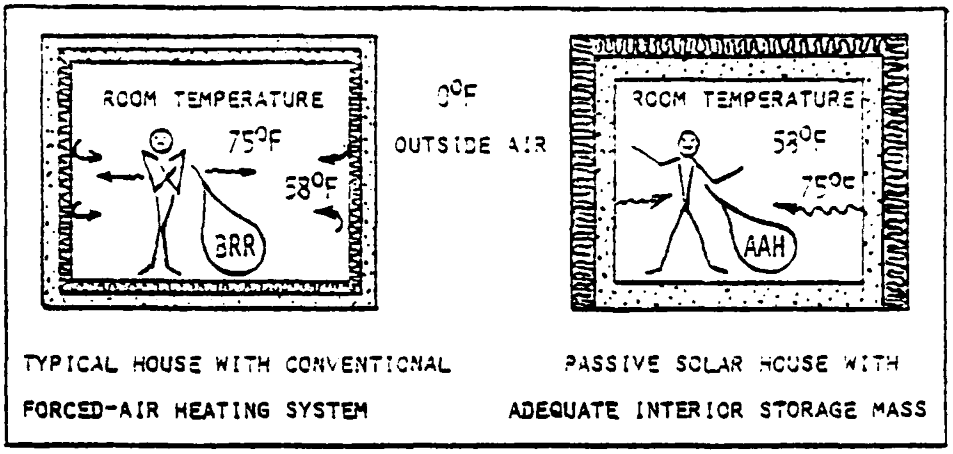



Figure 3.1 Influence of Wall Temperature on Human Comfort

passive systems, the collector (window) orientation is usually vertical or sloped, and the amount of radiation reaching the interior of the house depends on the type and number of glazings, the ground reflectance, atmospheric conditions (sky clearness, air pollution), cloud cover, and the sun's position in the sky (determined seasonally by latitude and time of day). Even less information is available on the sequence of clear and cloudy days and the percent sunshine actually received by the collector. But even where average data is available, conditions on any one day (or even monthly averages) can vary by ±30 percent or more.

Because of all these uncertainties, using averaged values in the design calculations will most likely not be a handicap in obtaining a good passive design which will perform adequately during all but very extreme years, if care is taken to get good heat distribution in the house, if climate-appropriate passive solar heat gain methods are applied (combinations of systems have an advantage here since they usually have different characteristics and peak performance during different times of the year) and especially if subsequently the house is built with top-quality construction. This last point cannot be overemphasized. The graphs and tabulated values for solar heat gain or radiation are given later in the report where the data is needed to complete the worksheets of the design procedure. In general, until more accurate information becomes available, the designer is advised to make reasonable adjustments for local conditions (i.e. increased cloudiness near mountains, air pollution near factories, reflective surfaces in front of collectors, etc.) when using the area-averaged data given in this manual. Estimates of these adjustments can be made through comparison with data from locations with similar conditions; after the designer has had some experience with passive systems design and operation, these adjustments may be made "intuitively".

## 3.2 Design Objectives for Warm, Humid Climate

A well-designed and well-built passive solar building in a climate with cold or cool winters performs the following functions:

1. It is a solar collector (by using south-facing windows, walls, and skylights, and sometimes also the roof).
2. It is a heat storehouse (by incorporating mass inside the building).
3. It is a heat trap (through good construction and insulation, including window night insulation).

These three have to be in a correctly-balanced relationship for the particular climatic conditions at the site. For locations with less than 1500 heating degree days and humid summers, the functions of the passive building must also include reduction of summer heat gain and humidity. In these locations, the important design objectives are, in this order:

1. Use of prevailing summer breeze for natural ventilation
2. Extensive summer shading
3. Reduction of humidity
4. Use of winter sun, some heat storage mass, adequate insulation
5. Building aspect ratio* = 1.6 - 1.8

These objectives can be achieved by incorporating the following features into the design of the building:

### A. For Florida (27°N to 31°N Latitude)

(a) Breezeways
(b) Vented attics
(c) Two-story construction with high, vented crawlspace
(d) Operable louvers, transoms, casement windows
(e) Open floor plan
(f) Chimney effect, belvederes, roof monitors

*This means the E-W axis it longer than the N-S axis of the building, with the N-S axis assigned a value of 1.

(g) Light colors inside, mildew-resistent light colors outside
(h) Shaded living areas
(i) Underground construction or earth cooling where water table is not too high
(j) Plants (inside and outside) located in shady areas
(k) Kitchen, laundry and bathrooms located "downwind" of the summer breeze
(l) Glazed-in porches used for winter heat gain and insulation, convertible to screened, shaded summer living areas

B. For Florida (25°N to 27°N Latitude) and Hawaii

(m) Design for outdoor living
(n) Exposed lots
(o) Galleries, terraces, shaded patios, breezeways, porches, pavillions
(p) Isolated laundry, kitchen
(q) Reflective roof
(r) Ground covers near the building (avoid heat-absorbing rocks, gravel etc.)
(s) Minimum E-W windows (unless needed for natural ventilation; must be well-shaded)
(t) Minimum interior walls, movable walls
(u) Large shade trees, good drainage

C. Gulf Coast

Items (a) through (h) and (k) as listed above
(v) Shaded doorways
(w) Earth cooling (if water table allows)
(x) Minimum heat storage mass
(y) Shaded balconies
(z) Insulated roof, exhaust fans, ceiling fans, elevated ceilings

In all these areas, groups of homes in high-density developments should be arranged such that they will not block the prevailing breeze from each other; paved areas must be shaded with trees.

### 3.3 Preliminary Design Data

Before definite sketches and calculations can be made for houses in locations with more than 500 heating degree days, the designer will need to assemble a variety of information on the planned building's site and use. Worksheets 1A, 1B and 1C have been provided for this purpose. The overall objective of the designer should be to produce a house that is both energy-efficient and livable (that is, it will be comfortable and meet the needs of the people living in it). Therefore, a family that is rarely home during working hours but does a lot of entertaining at night will need a different room layout than a family with preschool children who will benefit from brighter living spaces. In passive design, it is possible to build/design into the home a large degree of automatic/natural temperature control by careful placement and sizing of rooms (with proper zoning and buffer spaces), storage mass, heat-gaining and ventilating windows and shading devices, and in the selection of the most appropriate passive solar mechanisms. Such a building will be able to maintain reasonable comfort even during power failures or periods of fuel shortages.

Worksheet 1A asks for basic design information. This information defines the limits and restrictions on the building that will have to be carefully incorporated into the design. For example, if both access and best view are to the west, the entry will have to be provided with shelter, and the larger window size (for the view) will need to be compensated for with increased insulation and careful shading. Space is also provided for listing the special needs and wishes of the people who will live in the house; it is important to consider these in the design as much as possible within the building's construction budget. People will not be happy in a solar house if annoyed daily by a poor circulation pattern, insufficient storage areas, etc., even if passive heating (and cooling) are functioning well. If the house is to be built for sale, the focus can be on a specific group in the housing market, i.e. young families, professional people or older couples, and the design is made with their special needs in mind. These special features can then be used to make the solar home attractive to this group of buyers even outside its solar features.

## WORKSHEET 1A
## DESIGN INFORMATION

1. Location of building: ______________ Altitude: ______________
2. Building type (one or two story, split-level, etc.): ______________
3. Roof shape: ______________
4. Lot size: ______________ Special features: ______________
5. Lot orientation (in which direction will the house face the street?): ____
6. Building setbacks (check with local codes): ______________
7. Zoning restrictions and covenants: ______________
8. Lot access: ______________
9. Utility access: ______________
10. Lot slope, water runoff (erosion?), berming: ______________
11. Predominant direction of winter wind: ______ Velocity: _____ mph average
12. Predominant direction of summer breeze: _____ Velocity: _____ mph average
13. Direction of best view: ______________
14. Direction of worst view: ______________
15. Shading from neighboring houses, trees, etc.: ______________
16. Approximate floor area: ______________ Heated basement? ______________
17. Number of occupants: ______________
18. Number of bedrooms, baths: ______________
19. Other living spaces wanted: ______________
20. Life style of occupants and special needs (i.e. play area for children, space for entertaining, hobbies; space used during day, evening; special storage requirements; handicaps): ______________
21. Preferred patio location, other outdoor recreation areas: ______________
22. Occupants like the following features: ______________
23. Occupants dislike the following features: ______________

Worksheet 1B is used for sketching a space relationship diagram for the planned dwelling. Figure 3.2 illustrates different possibilities, depending on the requirements of the people and the lot constraints (access, size, shading, view, etc.). Even though the three designs shown in the example can be used in similar climatic zones (500 to 1500 heating degree days), different design conditions resulted in very different space relationships.

A study of the space relationship diagram will give some indication of the passive solar heating and cooling mechanisms that can be employed. Natural ventilation in the summer is of prime importance. Direct gain in the winter must be combined with provisions for summer shading. If living areas are to the north, clerestory windows (with roof overhangs) for direct gain can best be used; if no view is present, if privacy is desired or a bad view must be concealed, Trombe walls (or a glazed-in porch) can be chosen for the south wall. The Trombe walls may be used for induced summer ventilation. If there are no restrictions or preferences, it is best to begin the preliminary design with a moderate amount of direct gain to the important living spaces only and make modifications after some preliminary calculation results have been obtained.

Worksheet 1C will provide additional information and a checklist for energy-conservation measures that can/should be incorporated into the design and building specifications.

WORKSHEET 1B

SPACE RELATIONSHP DIAGRAM

Floor area: ______________ sq. ft.

Sketch the location of the main entry and the living, cooking, eating and sleeping areas; then mark the major wind directions and place kitchen, baths, utility, and laundry rooms downwind of the prevailing summer breeze. Use storage areas and garage/carport as buffer zones against winter winds and summer heat. Indicate the zoning barrier (■ ■ ■) and tentatively mark the location of auxiliary wood burners (✱) (if any). Areas thus marked will need to be designed so that they can be completed closed off from the remaining sections of the house during periods when auxiliary heating is necessary. Finally, show the direction(s) of the best view (and, optionally, undersirable views which will need to be screened). Indicate roof overhangs, porches and other means of shading, especially for E and W walls.

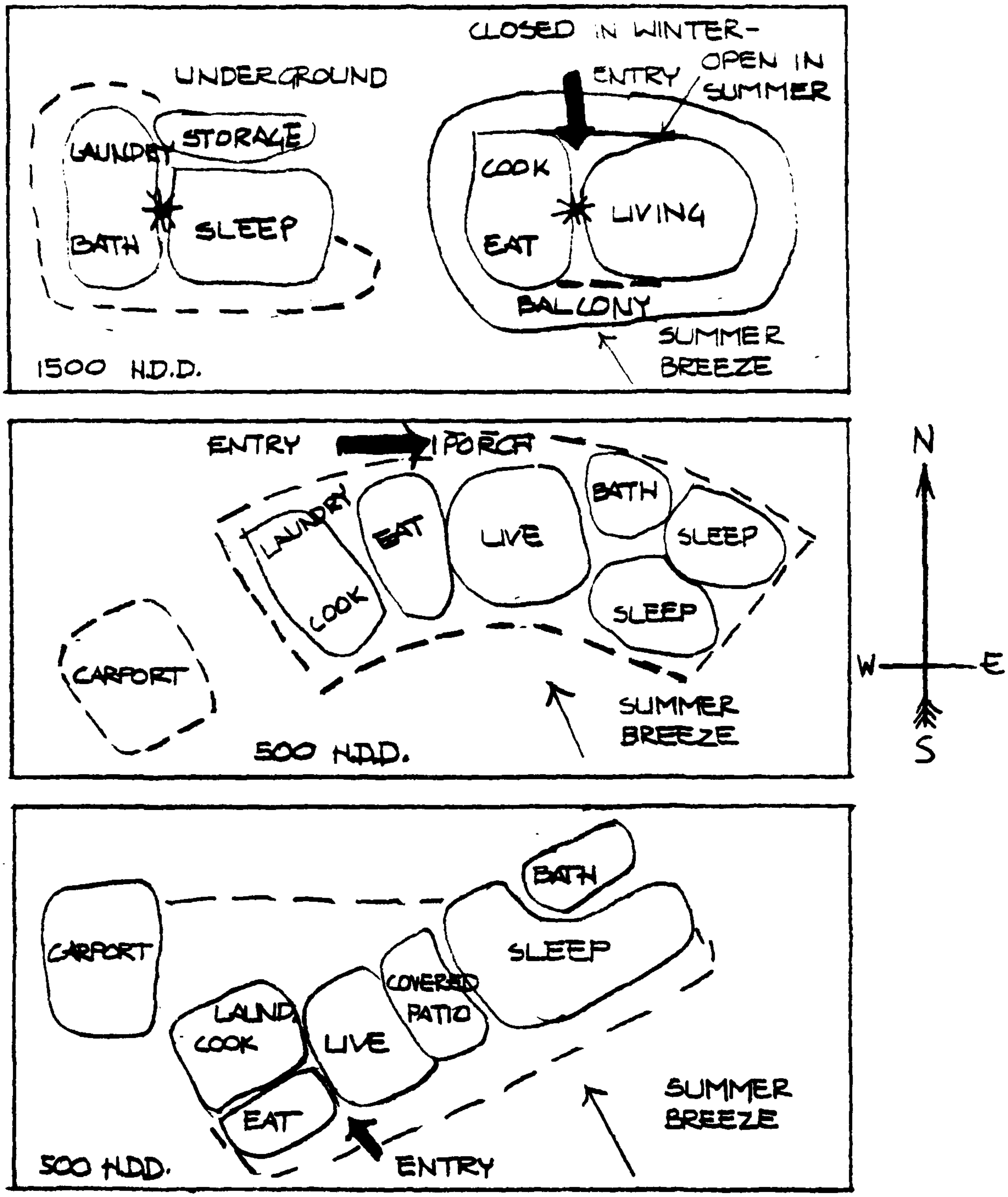



Figure 3.2 Examples of Space Relationship Diagrams

WORKSHEET 1C

ADDITIONAL INFORMATION AND CHECKLIST FOR ENERGY CONSERVATION

Building orientation is primarily broadside to prevailing summer breeze

Windbreaks are provided against winter storms. Where necessary, hurricane protection is provided.

Windows are of double-glazed casement or double-hung type? ________

Window areas to the east and west are minimized.

E and W walls are completely shaded in the summer.

Windows allow sufficient natural summer ventilation.

Windows are insulated at night by (insulated drapes, shades, movable louvers, interior or exterior shutters): ________

Can such shutters be used as hurricane protection if necessary? ____

Passive solar mechanisms included in the design are: ________

Storage mass is located at: ________

Are fans used for heat distribution or cooling?: ______ Where? ____

Is there a solar greenhouse? ________

Will plants in the house be away from direct sun? ________

Can humidity in the house be easily vented? ________

Is the main entry an air lock in the winter? ________

What type backup space heater is planned? ________

---

Will a solar water heater be used? _____ What type? ________

Solar tank location, size: ________

Collector location: ________ Type: ________ Area needed: ______

Heat exchanger(s): ________

Collector slope (approximately equal to latitude +10° is best): ____

---

Backup water heater, type, size, fuel: ________

Is the water heater isolated from the living space? ________

Energy-efficient applicances to be used are: ________

Fluorescent lights are to be used in: ________

Wood burner or stove? ________ Output: ________ Btu/hr

At this point, the first sketches of the design (including the passive solar heating and cooling method(s)) should be made because dimensions are needed for the design calculations that follow. A convenient scale to use is 1" = 10'. A floor plan may be sufficient for a simple design if window sizes are listed separately; otherwise, a sketch of the elevations should be included. From this sketch, Worksheet 1D (Building Dimensions) can then be completed.

A word of caution must be added at this point; do not expect to be able to design the perfect passive solar house -- this is impossible for at least three reasons: daily and yearly variations in the weather/climate, the living habits of people, and cost-effectiveness. It is, however, not too difficult to achieve a good design if the design is kept somewhat flexible, and if compromises are made reasonably and carefully between climatic conditions, people requirements and cost. As people live in the house, it may be necessary to "fine-tune" the design during or after the first year of operation. This should not be considered to be a flaw in the design but rather a sign of flexibility. For instance, roof overhangs in moderate and warmer climates may be either too long for cool springs and just right for the fall, or right in the spring and insufficient during the fall. The inhabitants will be most comfortable if they are left with some control over or method of adjustment in the amount of shading or, conversely, in the amount of solar heat getting into the house. In general, different combinations of passive solar heat gain mechanisms where warranted by the climate should be considered not only from the architectural standpoint (and cost), but also for the added measure of control possibilities that would be provided to the overall design. Another point to consider is that daily owner involvement in operating the movable window night insulation in winter and shading controls in the summer must be kept within reasonable bounds. Thus, if the budget allows, some automatic or semi-automatic controls are preferable, such as the "Skylid" window shutter, the insulated, motorized "Thermal Gate" quilted curtain, or in very extreme climates the "Bead Wall" window insulation. Climate control of course also includes the proper choice and location of backup heater(s) and air conditioning equipment.

WORKSHEET 1D

BUILDING DIMENSIONS
(for Worksheet 2)

| Orientation/ Type | Gross Wall Area, $ft^2$ Window Door Area, $ft^2$ Net Wall Area, $ft^2$ | Perimeter ft |
|---|---|---|
| | ( ) - [( )+( )] = ( ). | ( ) |
| Total NW<br>Total N<br>Total NE<br>Total E<br>Total SE<br>Total W<br>Total SW<br>Total S<br>Total Trombe<br>Total Air Lock | | |
| Total | ( ) - [( )+( )] = ( ). | ( ) |
| Roof | Gross Roof Area Skylights Net Roof Area<br>( ) - ( ) = ( ) | |

A more detailed discussion of backup heating (and of other design factors, such as solar water heating, lot selection, storage alternates) is given in Reference [4]. It is very important in warm, humid climates that excess solar heat gain and humidity be prevented from entering the house. The heat load calculations can be used to check out the winter solar heat gains needed for comfort. Although no specific calculation method is given for cooling, the designer must carefully incorporate shading, natural ventilation and zoning into the planned building in order to increase comfort and reduce summer energy consumption for cooling. For locations which require practically no winter heating (i.e. Southern Florida and Hawaii), calculations as given here are thus not required; however, cooling loads may be calculated using ASHRAE methods [6].

## 4. CALCULATION OF BUILDING HEAT LOSS

How well will the planned building perform as a heat trap? Building heat loss occurs in two ways: by conduction through the building envelope (or skin) and by infiltration of cold air. The total building heat loss is the sum of these two losses. Reducing heat loss (or in other words, the heating load) is the first objective in passive solar design, because insulation is more cost-effective than using large amounts of glazing and storage mass. A sufficient amount of insulation will also reduce summer heat gain.

### 4.1 Calculation of Building Skin Conductance

The primary design goal in a warm, humid climate is prevention of heat gain by isolating internal heat sources, using shading and increasing comfort by using natural ventilation. Large amounts of insulation are only needed in E-W walls and roofs if these cannot be shaded.

For locations with 500 to 1500 heating degree days (see Table 4.8), two sets of input information are needed to complete Worksheet 2: the area of the exterior surfaces and their U-value. Table 4.2 lists U-Values for typical construction, or ASHRAE values and methods may be used [6]. Table 4.3 lists R-factors for a number of building and insulation materials, Table 4.4 the R-factors for air layers and air spaces.

For each surface except the floor or basement, multiply the area with its U-value. Where there are large unheated airlock spaces, such as entry or garage, consider the wall between the airlock and the heated rooms as the building's skin. But because the temperature difference between the two sides of the wall is not as large as for an exterior wall, multiply the product of its U-value and surface area by two-thirds (if the doors will be kept shut except when needed for entry or exit).

The heat loss through the floor depends on the type of foundation used.

(a) Slab-on-Grade Construction
Calculate the product of F x P, where the value of F is obtained from Table 4.1 and P is the length of the slab edge (building perimeter).

(b) Crawlspace Under Joist Floors (No Vents)

Calculate the product of $Ah_c$, where

$h_c = 0.12$ (no insulation)

$h_c = 0.05$ (R-11 insulation)

$h_c = 0.03$ (R-19 insulation)

and A is the heated gross floor area.* Figure 4.1 can be used to find interpolated values.

(c) Vented Crawlspace

Calculate the product of UA, where A is the gross floor area and U is the reciprocal of the total R-value of the floor and insulation. It is recommended that the floor be carefully insulated in locations with more than 1000 heating degree days, or that the vents be closed in the winter.

(d) Heated Basement

Walls down to 4 ft below grade are treated like exterior walls, where heat loss equals U x A. Heat loss for walls lower than 4 ft below grade and in contact with firm soil is determined by calculating the product $h_bA$. The value of $h_b$ depends on the R-value of the insulation and can be taken from Figure 4.1. The heat loss through the floor is about half that of the below-grade walls for the same amount of insulation.

(e) Unheated Basement

Assume a similar heat loss pattern as for crawlspace. Good floor insulation is important between the heated living space and the unheated basement.

Table 4.5 gives a list of night insulation R-factors for single, double, and triple-glazed windows to achieve a given (assumed) average U-value for the window over a 24-hour day. If the window insulation will not be used for the full 14 hours (5 p.m. to 7 a.m. for example), then the R-factor of the window insulation must be increased above that given in Table 4.5.

Finally, on Worksheet 2, last column, determine the percentage contribution for the total losses of walls, windows and doors, roof, and floor.

*Gross floor area is measured from the outside of exterior wall studs (for frame walls) or exterior of masonry walls.

## WORKSHEET 2

## CALCULATION OF BUILDING SKIN CONDUCTANCE

| Surface Type | Net Area $ft^2$ | | U-value Btu/hr-°F-$ft^2$ | | U x Area Btu/hr-°F* | % of Total |
|---|---|---|---|---|---|---|
| North exterior wall | ____ | X | ____ | = | ____ | |
| East exterior wall | ____ | X | ____ | = | ____ | |
| West exterior wall | ____ | X | ____ | = | ____ | |
| South exterior wall | ____ | X | ____ | = | ____ | |
| South Trombe wall | ____ | X | ____ | = | ____ | |
| Air lock walls | ____ | X | ____ | = | ____ | |
| Total Wall Heat Loss | | | | | $\boxed{\phantom{00}}$ | ____ |
| Doors: Entry | ____ | X | ____ | = | ____ | |
| Patio | ____ | X | ____ | = | ____ | |
| Other | ____ | X | ____ | = | ____ | |
| North windows | ____ | X | ____ | = | ____ | |
| East windows | ____ | X | ____ | = | ____ | |
| West windows | ____ | X | ____ | = | ____ | |
| South windows | ____ | X | ____ | = | ____ | |
| Clerestory windows | ____ | X | ____ | = | ____ | |
| Sloped skylights | ____ | X | ____ | = | ____ | |
| Horizontal skylights | ____ | X | ____ | = | ____ | |
| Total Door/Window Heat Loss | | | | | $\boxed{\phantom{00}}$ | ____ |
| Roof | ____ | X | ____ | = | $\boxed{\phantom{00}}$ | ____ |
| Floor ** | ____ | X | ____ | = | $\boxed{\phantom{00}}$ | ____ |
| Total Building Skin Conductance (add boxed-in values) | | | | | ____ | 100 |

* The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

** Crawlspace = $Ah_c$ (see Figure 4.1)

Slab = F x P (see Table 4.1)

Heated basement = $UA_{\text{wall above grade}} + h_b A_{\text{wall below grade}} + h_c A_{\text{floor}}$

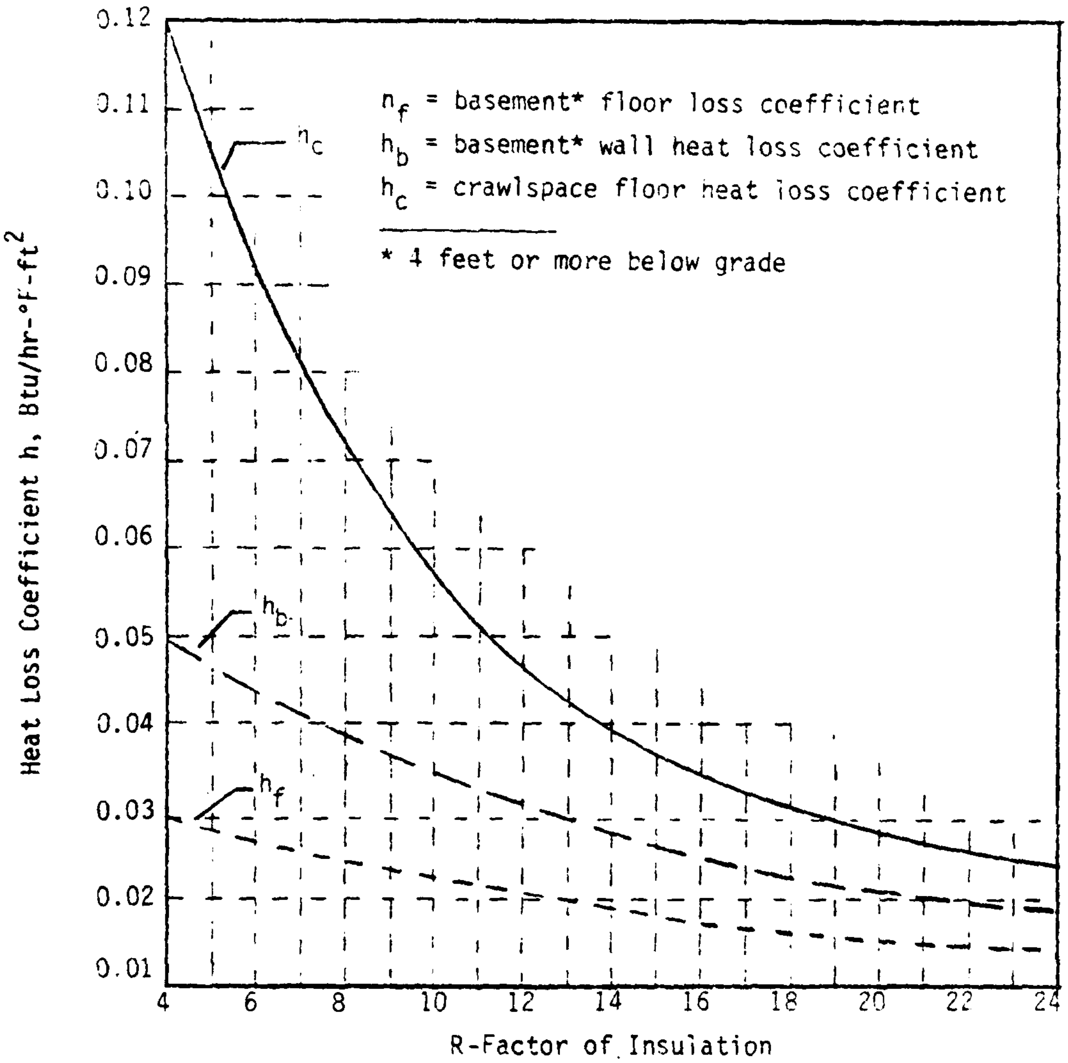
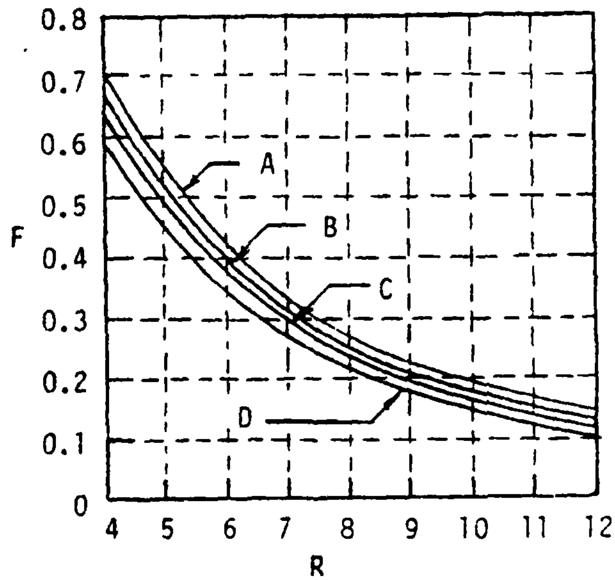



Figure 4.1 Heat Loss Coefficients for Basement and Crawlspace Heat Loss Calculations.

TABLE 4.1

Heat Loss Factors for Concrete Floor Slabs at Grade Level per Foot of Slab Edge

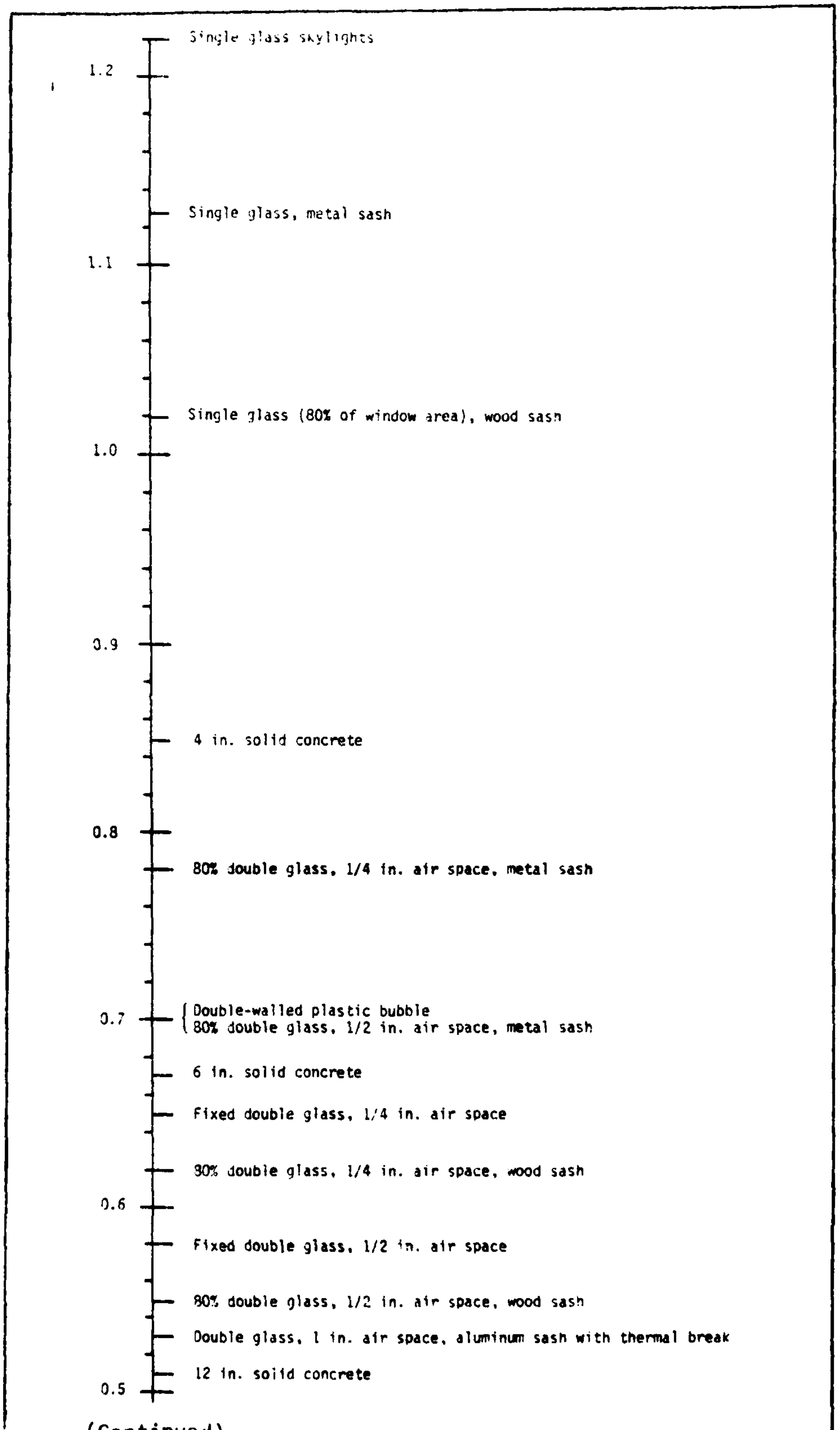
| Degree-Days | Depth of Insulation | F, Btu/hr-°F per ft Perimeter | | | | | |
|---|---|---|---|---|---|---|---|
| | | R-12 | R-10 | R-8 | R-6 | R-5 | R-2.5 |
| A, 2500 | 4-6 in. | 0.14 | 0.19 | 0.26 | 0.41 | 0.55 | 1.04 |
| B, 3500 | 12 in. | 0.13 | 0.18 | 0.25 | 0.39 | 0.52 | 1.00 |
| C, 4500 | 18 in. | 0.12 | 0.17 | 0.24 | 0.37 | 0.49 | 0.96 |
| D 5500, 6500, 7500 | 24 in. | 0.10 | 0.15 | 0.22 | 0.34 | 0.45 | 0.90 |




EXAMPLE: The slab heat loss for a home with a 140 ft perimeter in Zone D would be, using 3 inches of rigid polystyrene with an R-value of 3.85 per inch: (3 inches) x (3.85) = R - 11.5 which would give an F-value of about 0.11; thus the heat loss is 140(0.11) = 15 Btu/hr-°F. Instead, 24 in. wide and 2 in. thick polyurethane with an R-value of 5.88 per inch could have been used to get about the same heat loss. The values in Table 4.1 can be interpolated for the R-factor of the insulating material used.

TABLE 4.2

U-Values for Typical Building Construction
(for Passive Solar Houses), Btu/hr-ft$^2$-F°




(Continued)

TABLE 4.2 (Continued)

0.5

1-1/2 in. solid wood door

1-3/4 in. steel door with solid polystyrene core

80% triple glass, metal sash

8 in. common brick

0.4

Triple glass, fixed

80% triple glass, wood sash

1-1/2 in. solid wood door with metal storm door

12 in. common brick

0.3

1-1/2 in. solid wood door with 50% glass/wood storm door

10 in. adobe, 3/4 in. stucco wall (light color)

10 in. adobe, 3/4 in stucco wall (medium color)
Double-glazed uninsulated Trombe wall

0.2

Double-glazed water wall with night insulation

0.15 { Double glaze with well-setting thermal shutters (depending on R-value and installation)

20 in. adobe, 3/4 in. stucco wall

Double glazed Trombe wall with night insulation

0.10

Stucco wall, 2 x 4's with R-11 insulation, 1/2 in. gypsum board

Wood siding, 2 x 4's with R-11 insulation, 1/2 in. gypsum board

{ 24 in. adobe, 3/4 in. stucco wall, 1 in. foam (R-9) on exterior
4 in. common brick veneer, R-15 insulation, 1/2 in. gypsum board

Wood siding, 2 x 6's with R-18 insulation, 1/2 in gypsum board

0.05 10 in. adobe, 3/4 in. stucco wall, foam (R-18) on exterior

{ Wood siding or brick, R-4 board, 2 x 6's with R-19 insulation.
Roof with R-19 insulation

0.04

Double wall of 2 x 4's (offset, 24 in. O.C.) with air gap, R-22 insulation

24 in. adobe, 3/4 in. stucco wall, 2 in. foam (R-20) on exterior

0.03

} Roof with R-38 insulation (depends on deck layers, reflective surfaces, additional air spaces)

0.02

R-40 walls
R-80 roof

0.01

0

## TABLE 4.3 R-FACTORS OF BUILDING MATERIALS

(from Ref. [6])

| Material and Description | | Density ($lb/ft^3$) | R-Value per inch thickness | R-Value for listed thickness |
|---|---|---|---|---|
| **Building Boards, Panels, Flooring** | | | | |
| Asbestos-cement board | | 120 | 0.25 | -- |
| Asbestos-cement board | 1/8" | 120 | -- | 0.03 |
| Gypsum or plaster board | 3/8" | 50 | -- | 0.32 |
| Gypsum or plaster board | 1/2" | 50 | -- | 0.45 |
| Plywood (see Siding Materials) | | 34 | 1.25 | -- |
| Sheathing, wood fiber (impregnated or coated) | 25/32" | 20 | -- | 2.06 |
| Wood fiber board (laminated or homogenous) | | 26 | 2.38 | -- |
| Wood fiber, hardboard type | | 65 | 0.72 | -- |
| Wood fiber, hardboard type | 1/4" | 65 | -- | 0.18 |
| Wood subfloor | 25/32" | -- | -- | 0.98 |
| Wood, hardwood finish | 3/4" | -- | -- | 0.68 |
| **Building Paper** | | | | |
| Vapor-permeable felt | | -- | -- | 0.06 |
| Vapor-seal, 2 layers of mopped 15 lb felt | | -- | -- | 0.12 |
| Vapor-seal plastic film | | -- | -- | negl. |
| **Finish Materials** | | | | |
| Carpet and fibrous pad | | -- | -- | 2.08 |
| Carpet and rubber pad | | -- | -- | 1.23 |
| Cork tile | 1/8" | -- | -- | 0.28 |
| Terrazzo | 1" | -- | -- | 0.08 |
| Tile (asphalt, linoleum, vinyl, rubber) | | -- | -- | 0.05 |
| Gypsumboard | 1/2" | -- | -- | 0.45 |
| Gypsumboard | 5/8" | -- | -- | 0.56 |
| Hardwood flooring | 25/32" | -- | -- | 0.68 |
| **Insulating Materials** | | | | |
| Blankets and Batts: | | | | |
| Mineral wool, fibrous form (from rock, slag or glass) | | 0.5 | 3.12 | -- |
| | | 1.5-4.0 | 3.70 | -- |
| Wood fiber | | 3.2-3.6 | 4.00 | -- |
| Boards and Slabs: | | | | |
| Cellular glass | 30°F | 9 | 2.70 | -- |
| Corkboard | 30°F | 6.5-8.0 | 3.85 | -- |
| | 30°F | 12 | 3.45 | -- |
| Glass fiber | 90°F | 4.0-9.0 | 3.85 | -- |
| | 30°F | | 4.55 | -- |
| Expanded rubber (rigid) | 75°F | 4.5 | 4.55 | -- |
| Expanded polyurethane (R-11 blown; 1" thickness or more) | 100°F | 1.5-2.5 | 5.56 | -- |
| | 25°F | | 5.88 | -- |
| Expanded polystyrene, extruded | 75°F | 1.9 | 3.85 | -- |
| | 30°F | | 4.17 | -- |

| Material and Description | | Density ($lb/ft^3$) | R-Value per inch thickness | R-Value for listed thickness |
|---|---|---|---|---|
| Expanded polystyrene molded beads | 75°F | 1.0 | 3.57 | -- |
| | 30°F | | 3.85 | -- |
| Mineral fiberboard, felted core or roof insulation | | 16-17 | 2.94 | -- |
| acoustical tile (ave.) | | 21 | 2.73 | -- |
| Mineral fiberboard, molded acoustical tile[1] | | 23 | 2.38 | -- |
| Wood or cane fiberboard acoustical tile | 1/2" | -- | -- | 1.19 |
| interior finish | | 15 | 2.86 | -- |
| Insulating roof deck | 1" | -- | -- | 2.78 |
| | 2" | -- | -- | 5.56 |
| | 3" | -- | -- | 8.33 |
| Shredded wood (cemented, preformed slabs) | | 22 | 1.67 | -- |
| Loose Fills: | | | | |
| Macerated paper or pulp | | 2.5-3.5 | 3.57 | -- |
| Mineral wool | 90°F | 2.0-5.0 | 3.33 | -- |
| | 30°F | | 4.10 | -- |
| Perlite (expanded | 90°F | 5.0-8.0 | 2.63 | -- |
| | 30°F | | 2.74 | -- |
| Vermiculite (expanded) | 90°F | 7.0-8.2 | 2.08 | -- |
| | 30°F | | 2.27 | -- |
| Sawdust or shavings | | 0.8-15 | 2.22 | -- |
| **Masonry Materials, Concretes** | | | | |
| Cement mortar | | 116 | 0.20 | -- |
| Gypsum-fiber concrete (87½% gypsum, 12½% concrete) | | 51 | 0.60 | -- |
| Lighweight aggregates (expanded shale, clay or slate; expanded slags, or cinders; pumice; perlite or vermiculite; cellular concretes) | | 120 | 0.19 | -- |
| | | 100 | 0.28 | -- |
| | | 80 | 0.40 | -- |
| | | 60 | 0.59 | -- |
| | | 40 | 0.86 | -- |
| | | 20 | 1.43 | -- |
| Sand and gravel or stone aggregate (oven dried) | | 140 | 0.11 | -- |
| Sand and gravel or stone aggregate (not dried) | | 140 | 0.08 | -- |
| Stucco | | 116 | 0.20 | -- |
| **Masonry Units** | | | | |
| Brick, common[1] ) typical value | | 120 | 0.20 | -- |
| Brick, face[1] ) | | 130 | 0.11 | -- |
| Clay tile, hollow | | | | |
| 1 cell deep | 3" | -- | -- | 0.80 |
| 1 cell deep | 4" | -- | -- | 1.11 |
| 2 cells deep | 6" | -- | -- | 1.52 |
| 2 cells deep | 8" | -- | -- | 1.85 |
| 3 cells deep | 10" | -- | -- | 2.22 |
| 3 cells deep | 12" | -- | -- | 2.50 |

Continued

# Table 4.3 Continued

| Material and Description | | Density ($lb/ft^3$) | R-Value per inch thickness | R-Value for listed thickness |
|---|---|---|---|---|
| Concrete block, 3 oval core | | | | |
| Sand and gravel aggregate | 4" | -- | -- | 0.71 |
| | 8" | -- | -- | 1.11 |
| | 12" | -- | -- | 1.28 |
| Cinder aggregate | 3" | -- | -- | 0.86 |
| | 4" | -- | -- | 1.11 |
| | 8" | -- | -- | 1.72 |
| | 12" | -- | -- | 1.89 |
| Lightweight aggregate | 3" | -- | -- | 1.27 |
| (expanded shale, clay or slate | 4" | -- | -- | 1.50 |
| or slag, pumice) | 8" | -- | -- | 2.00 |
| | 12" | -- | -- | 2.72 |
| Concrete blocks, rectangular core | | | | |
| Sand and gravel aggregate | | | | |
| 2 core, 36 lb* | 8" | -- | -- | 1.04 |
| same, filled cores** | | -- | -- | 1.93 |
| Lightweight aggregates | | | | |
| 3 core, 19 lb* | 6" | -- | -- | 1.65 |
| same, filled cores** | | -- | -- | 2.99 |
| 2 core, 24 lb* | 8" | -- | -- | 2.18 |
| same, filled cores** | | -- | -- | 5.03 |
| 3 core, 38 lb* | 12" | -- | -- | 2.48 |
| same, filled cores** | | -- | -- | 5.82 |
| Stone, lime or sand | | -- | 0.08 | -- |
| Granite, marble | | 150-175 | 0.05 | -- |
| Adobe | 10" | -- | -- | 2.78 |
| | 14" | -- | -- | 3.89 |
| Plastering Materials | | | | |
| Cement plaster, sand aggregate | | 116 | 0.20 | -- |
| Gypsum plaster | | | | |
| Lightweight aggregate | 1/2" | 45 | -- | 0.32 |
| Lightweight aggregate | 3/8" | 45 | -- | 0.39 |
| Same, on metal lath | 3/4" | -- | -- | 0.47 |
| Perlite aggregate | | 45 | 0.67 | -- |
| Sand aggregate | | 105 | 0.18 | -- |
| Same, on metal lath | 3/4" | -- | -- | 0.10 |
| Same, on wood lath | 3/4" | -- | -- | 0.40 |
| Vermiculite aggregate | | 45 | 0.59 | -- |
| Roofing Materials | | | | |
| Asbestos-cement shingles | | 120 | -- | 0.21 |
| Asphalt roll roofing | | 70 | -- | 0.15 |
| Built-up roofing | 3/8" | 70 | -- | 0.44 |
| Slate roofing | 1/2" | -- | -- | 0.05 |
| Wood shingles | | -- | -- | 0.94 |
| Built-up roofing | | -- | -- | 0.33 |

| Material and Description | | Density ($lb/ft^3$) | R-Value per inch thickness | R-Value for listed thickness |
|---|---|---|---|---|
| Siding Materials | | | | |
| Shingles | | | | |
| Asbestos-cement | | 120 | -- | 0.21 |
| Wood, 16" with 7 1/2" exposure | | -- | -- | 0.80 |
| Wood, double 16" with 12" exposure | | -- | -- | 1.19 |
| Wood, plus insulating backer board | 5/16" | -- | -- | 1.40 |
| Siding | | | | |
| Asbestos-cement lapped | 1/4" | -- | -- | 0.21 |
| Asphalt rool siding | | -- | -- | 0.15 |
| Asphalt insulating siding | 1/2" | -- | -- | 1.46 |
| Wood, drop (1" x 8") | | -- | -- | 0.79 |
| Wood, drop (1/2" x 8" lapped) | | -- | -- | 0.81 |
| Wood, bevel (3/4" x 10" lapped) | | -- | -- | 1.05 |
| Plywood, lapped | 3/8" | -- | -- | 0.59 |
| Plywood | 1/4" | -- | -- | 0.31 |
| | 3/8" | -- | -- | 0.47 |
| | 1/2" | -- | -- | 0.62 |
| | 5/8" | -- | -- | 0.78 |
| | 3/4" | -- | -- | 0.94 |
| Stucco | | 116 | 0.20 | -- |
| Sheathing, insulating board | 1/2" | -- | -- | 1.32 |
| (regular density) | 25/32" | -- | -- | 2.04 |
| Woods | | | | |
| Hardwoods (maple, oak) | | 45 | 0.91 | -- |
| Softwoods (fir, pine) | | 32 | 1.25 | -- |
| | 25/32" | 32 | -- | 0.98 |
| | 1-5/8" | 32 | -- | 2.03 |
| | 2-5/8" | 32 | -- | 3.28 |
| | 3-5/8" | 32 | -- | 4.55 |
| Particleboard | | | | |
| Low density 37#/$ft^3$ | 1" | -- | -- | 1.85 |
| Medium density 50#/$ft^3$ | 1" | -- | -- | 1.06 |
| High density 62.5#/$ft^3$ | 1" | -- | -- | 0.85 |
| Wood Doors | | | | |
| Solid core | 1" | -- | -- | 1.56 |
| | 1-1/4" | -- | -- | 1.82 |
| | 1/1/2" | -- | -- | 2.04 |
| | 2" | -- | -- | 2.33 |

*Weights of blocks approximately 7-5/8" high by 15-3/8" long.

**Vermiculite, perlite, or mineral wool insulation.

TABLE 4-4

R-VALUES OF AIR FILMS AND AIR SPACES

(from Ref. [6])

| Type and Orientation of Air Film | Direction of Heat Flow | R-value for Air Film On: Non-reflective surface | Fairly reflective surface | Highly reflective surface |
|---|---|---|---|---|
| Still air: | | | | |
| Horizontal | up | 0.61 | 1.10 | 1.32 |
| Horizontal | down | 0.92 | 2.70 | 4.55 |
| 45° slope | up | 0.62 | 1.14 | 1.37 |
| 45° slope | down | 0.76 | 1.67 | 2.22 |
| Vertical | across | 0.68 | 1.35 | 1.70 |
| Moving Air: | | | | |
| 15 mph wind | any* | 0.17 | — | — |
| 7½ mph wind | any† | 0.25 | — | — |

| Orientation & Thickness of Air Space | Direction of Heat Flow | R-value for Air Space Facing:‡ Non-reflective surface | Fairly reflective surface | Highly reflective surface |
|---|---|---|---|---|
| Horizontal 1/4" | up* | 0.87 | 1.71 | 2.23 |
| 4" | | 0.94 | 1.99 | 2.73 |
| 3/4" | up† | 0.76 | 1.63 | 2.26 |
| 4" | | 0.80 | 1.87 | 2.75 |
| 3/4" | down* | 1.02 | 2.39 | 3.55 |
| 1-1/2" | | 1.14 | 3.21 | 5.74 |
| 4" | | 1.23 | 4.02 | 8.94 |
| 3/4" | down† | 0.84 | 2.08 | 3.25 |
| 1-1/2" | | 0.93 | 2.76 | 5.24 |
| 4" | | 0.99 | 3.38 | 8.03 |
| 45° slope 3/4" | up* | 0.94 | 2.02 | 2.78 |
| 4" | | 0.96 | 2.13 | 3.00 |
| 3/4" | up† | 0.81 | 1.90 | 2.81 |
| 4" | | 0.82 | 1.98 | 3.00 |
| 3/4" | down* | 1.02 | 2.40 | 3.57 |
| 4" | | 1.08 | 2.75 | 4.41 |
| 3/4" | down† | 0.84 | 2.09 | 3.34 |
| 4" | | 0.90 | 2.50 | 4.36 |
| Vertical 3/4" | across* | 1.01 | 2.36 | 3.48 |
| 4" | | 1.01 | 2.34 | 3.45 |
| 3/4" | across† | 0.84 | 2.10 | 3.28 |
| 4" | | 0.91 | 2.16 | 3.44 |

‡One side of the air space is a non-reflective surface.
*Winter conditions.
†Summer conditions.

TABLE 4.5

Average Window U-Values (24 Hours) and
Corresponding R-Factor of Night Insulation (14 Hours)
for Single, Double and Triple Glazing

| 24-Hour Average U-Value Used in Heat Loss Calculations | R-Factor of Night Insulation Used 14 Hours (incl. Air Space) | | |
|---|---|---|---|
| | Single Glazing | Double Glazing | Triple Glazing |
| 0.56 | 1.4 | | |
| 0.52 | 1.6 | | |
| 0.50 | 1.7 | | |
| 0.46 | 2.0 | 0.4 | |
| 0.45 | 2.1 | 0.5 | |
| 0.44 | 2.2 | 0.6 | |
| 0.43 | 2.3 | 0.7 | |
| 0.42 | 2.4 | 0.8 | |
| 0.41 | 2.5 | 0.9 | |
| 0.40 | 2.6 | 1.0 | |
| 0.395 | 2.65 | 1.05 | |
| 0.39 | 2.7 | 1.1 | |
| 0.38 | 2.85 | 1.2 | |
| 0.37 | 3.0 | 1.35 | |
| 0.36 | 3.1 | 1.5 | |
| 0.35 | 3.2 | 1.6 | |
| 0.34 | 3.35 | 1.75 | |
| 0.33 | 3.5 | 1.9 | |
| 0.30 | 4.0 | 2.15 | |
| 0.29 | 4.25 | 2.4 | 1.0 |
| 0.28 | 4.5 | 2.8 | |
| 0.27 | 4.75 | 3.0 | |
| 0.26 | 5.0 | 3.25 | |
| 0.25 | 5.2 | 3.5 | 2.0 |
| 0.24 | 5.4 | 3.75 | |
| 0.23 | 5.7 | 4.0 | |
| 0.22 | 6.0 | 4.5 | 3.0 |
| 0.21 | 6.4 | 5.0 | |
| 0.20 | 6.9 | 5.5 | |
| 0.19 | | | 4.0 |
| 0.17 | | | 5.0 |
| 0.16 | | | 6.0 |
| 0.15 | | 8.2 | |
| 0.14 | | | 7.0 |
| 0.13 | | | 8.0 |

TABLE 4.6

Recommended Ranges for Surface Heat Losses in Direct Gain Passive Solar Houses (in Percent)

| Surface | One-Story House | Two-Story House |
|---|---|---|
| Exterior Walls | 20-25% | 25-30% |
| Windows and Doors | 45-50% | 50-55% |
| Roof | 10-15% | 5-10% |
| Slab/Floor | 15-20% | 10-15% |

If the distribution of the building skin conductance for a direct-gain building falls quite a bit outside the percentage ranges indicated in Table 4.6, the design and building specifications should be reconsidered. Can window and door openings on the east, north and west sides of the house be reduced without reducing summer ventilation or natural lighting and still comply with local building code requirements? Can the building shape be made more compact (the less wall area, the less heat is lost)? Can wall, roof, slab edge insulation be increased? Can window glass, shutter or curtain U-value be improved?

If the design includes a Trombe wall or greenhouse, the calculated values will not fit exactly into the ranges given in Table 4.6; wall losses for the walls will be higher and for windows lower for Trombe wall designs, with the opposite being true for exposed greenhouse applications. Heat loss calculations following the method here take the loss of the Trombe wall into account in finding the building skin conductance and thermal load; some other methods, such as those developed by Balcomb [7] do not. In retrofit projects, it may not be possible to bring the building's heat losses within the recommended range without a very great expenditure of money, time and trouble. For apartment houses, heat loss depends on the location of each unit, with the ground floor apartments at each end having generally the highest losses, followed by the end apartments on the top floor; interior units have the smallest losses. Heating requirements among these units can be equalized somewhat by choosing much better window night insulation for the more exposed apartments.

## 4.2 Calculation of Infiltration Load and Modified Building Heat Loss Coefficient $C_B$

Worksheet 3 is used to calculate the infiltration load and the modified building heat loss coefficient. Volume is the gross floor area of the heated space times the average ceiling height. The heat capacity of air depends on altitude and is

$C_p$ (sea level) = 0.018 Btu/ft$^3$-°F
$C_p$ (1000 ft) = 0.0175 Btu/ft$^3$-°F
$C_p$ (2000 ft) = 0.0165 Btu/ft$^3$-°F
$C_p$ (3000 ft) = 0.016 Btu/ft$^3$-°F
$C_p$ (4000 ft) = 0.155 Btu/ft$^3$-°F
$C_p$ (5000 ft) = 0.015 Btu/ft$^3$-°F
$C_p$ (6000 ft) = 0.0145 Btu/ft$^3$-°F
$C_p$ (7000 ft) = 0.014 Btu/ft$^3$-°F
$C_p$ (8000 ft) = 0.0135 Btu/ft$^3$-°F
$C_p$ (9000 ft) = 0.013 Btu/ft$^3$-°F

The infiltration load is the heat needed to warm the cold air seeping into the building through even the tiniest cracks, such as around windows, doors, and where two different building materials meet, as for example between slab and framing.

The air change per hour (ACH) is a very important parameter; unfortunately, it can only be roughly estimated. A well-built solar house with very tight windows, caulking, weatherstripping, storm doors, air lock spaces, enclosed fireplace, few vents, some berming and landscaping with wind breaks, etc., can be assumed to have from 0.3 to 0.6 ACH, depending on the amount of insulation and quality of construction. If construction cannot be closely supervised, if the house is located in a very exposed area, and if air locks have been omitted because of cost-cutting, if the occupants are heavy smokers (and if winter winds come from the same direction as summer breezes), then it is safer to assume a minimum of 3/4 ACH or more. A well-built conventional house is assumed to have an ACH = 1. An older home with sliding windows could have an ACH of 1-1/2 or more. To reduce infiltration, careful attention must be paid to areas where cold air can enter, i.e. electrical outlets and piping in exterior walls, and skylights and vents through the roof. Fireplaces should be equipped with glass screens and a fresh-air duct with damper, or air-tight stoves should be used instead; however, the warmer the climate, the less strictly these last guidelines and requirements need to be followed.

WORKSHEET 3

CALCULATION OF INFILTRATION LOAD AND
MODIFIED BUILDING HEAT LOSS COEFFICIENT $C_B$

House Volume = Gross Floor Area x Ceiling Height =(      )(      )=____

Infiltration Load = Volume x $C_p$ x ACH          ACH = Air Change/Hour

= (      ) x (      ) x (      )

= ________ Btu/hr-°F

Modified Building Heat Loss Coefficient, $C_B$

= [Building Skin Conductance* + Infiltration Load]

= 24 [(      ) + (      )] = 24 (      )

= ____________________ Btu/D.D.

Gross Heated Floor Area of Building = ________ $ft^2$

$C_B$/A = (      ) / (      )

= ____________ Btu/$ft^2$-D.D.          D.D. = Degree Days**

* From Worksheet 2.

**"Degree Days" is an indication of the "coldness" of the climate for heating calculations; the degree-day value for a particular day is the difference between the average daily outdoor temperature and 65°F; the data is usually given in monthly and yearly totals.

TABLE 4.7

Recommended Design Heat Loss Range for Passive Solar Houses

| Heating Degree Day Range | $C_B/A$ (Btu/ft$^2$-D.D.) |
|---|---|
| 500 - 2000 | 5.5 - 8.0* |
| 2000 - 4000 | 4.5 - 6.5 |
| 4000 - 6000 | 3.5 - 5.5 |
| 6000 - 8000 | 2.5 - 4.5 |
| Above 8000 | 1.5 - 3 |

*Use lower values if refrigerated air conditioning will be used.

Table 4.7 is given as a checkpoint of the thermal performance of the design, to show how well the house will perform as a thermal storehouse. It has been compiled from published data on a number of passive direct gain solar houses that use only wood stoves as backup heaters. The calculated $C_B/A$ should fall within the indicated range for passive solar homes that expect to gain over 80 percent of their heat load by solar. Values toward the lower limit within a given range of Table 4.7 should be achieved by larger houses and for locations towards the upper degree day limit within the zone. Houses with extensive uninsulated Trombe walls will have values somewhat exceeding these numbers. Note that houses with construction and insulation yielding these values will exceed FHA and TEA (1975) standards [8] by a factor of at least 2. The proposed BEPS standards, for some regions in the U.S., are even less strict than present FHA standards; as written, they do not encourage the use of passive solar. It is of course possible to do even better than these guidelines (Table 4.7); the building in this case would be extremely well-built and insulated for the particular winter climate; one should, however, investigate the cost-effectiveness and the building's summer performance (i.e. are enough openings left for efficient natural ventilation?). If the calculated $C_B/A$ is higher than the indicated range, the building specifications (U-values, dimensions/shape) should be reviewed in terms of the design objectives. If no changes are desired at this point, the designer should proceed with the calculations; later the choice can be made to either increase solar collection if possible or decrease heat loss depending on which is more practical and economical. For massive adobe construction, the "effective U-values" as developed by the University of New Mexico [9] may be used in these calculations for the walls only, not for the windows. Retrofits may have difficulty achieving such small heat loss factors without a large investment in added insulation. The cost-effectiveness of each case should be evaluated individually. The solution will most likely be a compromise between a somewhat higher heat loss (or summer heat gain) at lower cost. Also, retrofits are usually equipped with a full-size backup, thus a larger heat loss is not as critical here as for a new passive design with just a small backup.

For the purposes of this design procedure (under this Navy contract), Table 4.8 lists heating degree days for some representative locations. More accurate local information may be available from local Chambers of Commerce. Yearly and even monthly totals can vary tremendously from one year to the next, thus using area-averaged values should be adequate to get an overall indication of the performance of the design during all but very extreme conditions. Reference [13] also lists heating degree data for many U.S. locations.

TABLE 4.8
Heating Degree Days for Warm, Humid Navy Locations
(Source: Ref. [10])

| Location | Total | J | A | S | O | N | D | J | F | M | A | M | J |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jacksonville, FL<br>Pensacola, FL<br>New Orleans, LA<br>Houston, TX | 1400 | - | - | - | - | 190 | 350 | 400 | 280 | 180 | - | - | - |
| Orlando, FL<br>Tampa, FL<br>Brownsville, TX<br>Corpus Christi, TX | 800 | - | - | - | - | 80 | 200 | 230 | 170 | 120 | - | - | - |
| Miami Beach, FL<br>Key West, FL | 200 | - | - | - | - | - | 50 | 70 | 60 | 20 | - | - | - |
| Hawaii, except for mountain peaks, has no heating degree days. | | | | | | | | | | | | | |

## 4.3 Calculation of Building Net Heating Load Profile

In this step, the modified building heat loss coefficient $C_B$ (from Worksheet 3) is used with the heating degree day information in Table 4.8 to find the thermal load of the building. In Worksheet 4, the estimated internal heat source contribution must also be listed in order to obtain the net thermal load; approximate values are given in Table 4.9. In conventional houses, the heat from the internal sources is used to raise the temperature from the 65° base (used in the number of heating degree days) to a more comfortable 68 to 70°F and is thus not separately taken into account. In well-insulated passive solar homes internal heat sources are important in reducing the thermal load and must thus be taken into account. Many passive homes with sufficient storage are quite comfortable at 65°F. The monthly heating degree days are multiplied with the value of $C_B$ to get the gross thermal load in million Btu/month (or MBtu/month). The internal heat contribution by people, lights and appliances is then subtracted to get the net thermal load of the building, that is the heat needed to be supplied by other sources such as solar and the backup heater.

Table 4.9
Contribution of Internal Heat Sources

| |
|---|
| 300,000 Btu/month per adult per 24-hour occupancy |
| 1,000,000 Btu/month for kitchen appliances and lights (2000 ft$^2$ house) |
| 200,000 Btu/month for washer/dryer if located in heated area |
| 100,000 Btu/month for water heater if located in heated area |

These figures for internal heat contribution are rough estimates; they can be calculated more accurately using ASHRAE methods [6]; however, since other assumptions such as infiltration are not that accurate (and depend on the occupants' living pattern), extreme accuracy is not needed. If an outdoor clothesline will be used frequently in the winter, this will reduce heat gain by 100,000 Btu/month. If the water heater and laundry are isolated from the living area, their useful heat contribution is minimal and should not be counted. Also, if little storage mass will be provided in the house, only two-thirds of the internal heat source contribution should be counted and entered in Worksheet 4. For a very small house (or a small family) the figures for lights, applicances and water heater should be reduced; also use smaller values if the family is a very energy-conscious and careful user of energy. In estimating the internal heat contribution, caution is advised when there is any doubt about the future energy consumption pattern of the occupants.

WORKSHEET 4

CALCULATION OF BUILDING THERMAL LOAD PROFILE

Modified Building Heat Loss Coefficient $C_B$ from Worksheet 3 = _____ Btu/D.D.

| Month | Degree Days per Month | $\times C_B$ | = | Gross Thermal Load, MBtu/month | – | Internal Heat Sources, MBtu/month | = | Net Thermal Load, MBtu/month |
|---|---|---|---|---|---|---|---|---|
| Aug. | _____ | $\times C_B$ | = | ______ | – | ______ | = | ________ |
| Sept. | _____ | $\times C_B$ | = | ______ | – | ______ | = | ________ |
| Oct. | | | | | | | | |
| Nov. | | | | | | | | |
| Dec. | | | | | | | | |
| Jan. | | | | | | | | |
| Feb. | | | | | | | | |
| Mar. | | | | | | | | |
| Apr. | | | | | | | | |
| May | | | | | | | | |
| Jun. | | | | | | | | |
| Jul. | | | | | | | | |

MBtu = Million Btu

## 5. CALCULATION OF SOLAR HEAT GAIN AND AUXILIARY LOAD

How well will the designed building perform as a solar collector? To calculate the solar heating contribution, data on average monthly solar heat gain through south-facing glazing is needed, as given in Figure 5.2. Figure 5.3 gives values for incident solar radiation on a south-facing surface tilted 37° as a convenience for solar water heater calculations. Data for these figures have been assembled from a number of sources, i.e. References [10, 11, 12]. A judgment has to be made by the designer on the basis of local conditions in adjusting the average values more accurately up or down. Worksheet 5 must be completed for each solar heating mechanism present in the design.

### 5.1 Effectiveness Factor and Solar Data

To complete Worksheet 5, the net effective collector area must be determined. This is a combination of frame shading, type and number of glazings and the solar heat gain mechanism efficiency and can be calculated by using the factors listed in Table 5.1. The gross collector area (usually taken from the overall dimensions of the window) is multiplied by a frame shading factor (0.95 for the narrow sashes of fixed windows, 0.8 or less for wider wood sashes and windows with many small panes). It is assumed that window screens are removed and glazing is cleaned in the winter to allow maximum heat gain. The window (or collector) area is then additionally multiplied by the "effectiveness" factor, depending on the glazing and collecting method used, and the resulting number is listed on the top of Worksheet 5. The purpose of the "effectiveness" factor is to provide an adjustment for the efficiencies and operational characteristics of the various passive solar heat gain mechanisms, so that a single solar estimator curve can be used for the combined heat gain. The values for Trombe walls have been checked against Balcomb's work [7], those for direct gain and solar roofs against actual operating experience. The value for sunspace (a feature of more complex designs) and for roof ponds are estimates and need verification. At present, these factors can be used with a good degree of reliability in climates which have over 60 percent or more monthly possible sunshine (Figure 5.1). For climates that have considerably more cloudy days in winter, and for hot, humid areas, both of which are designed with smaller storage capability, it is recommended that the effectiveness factor be

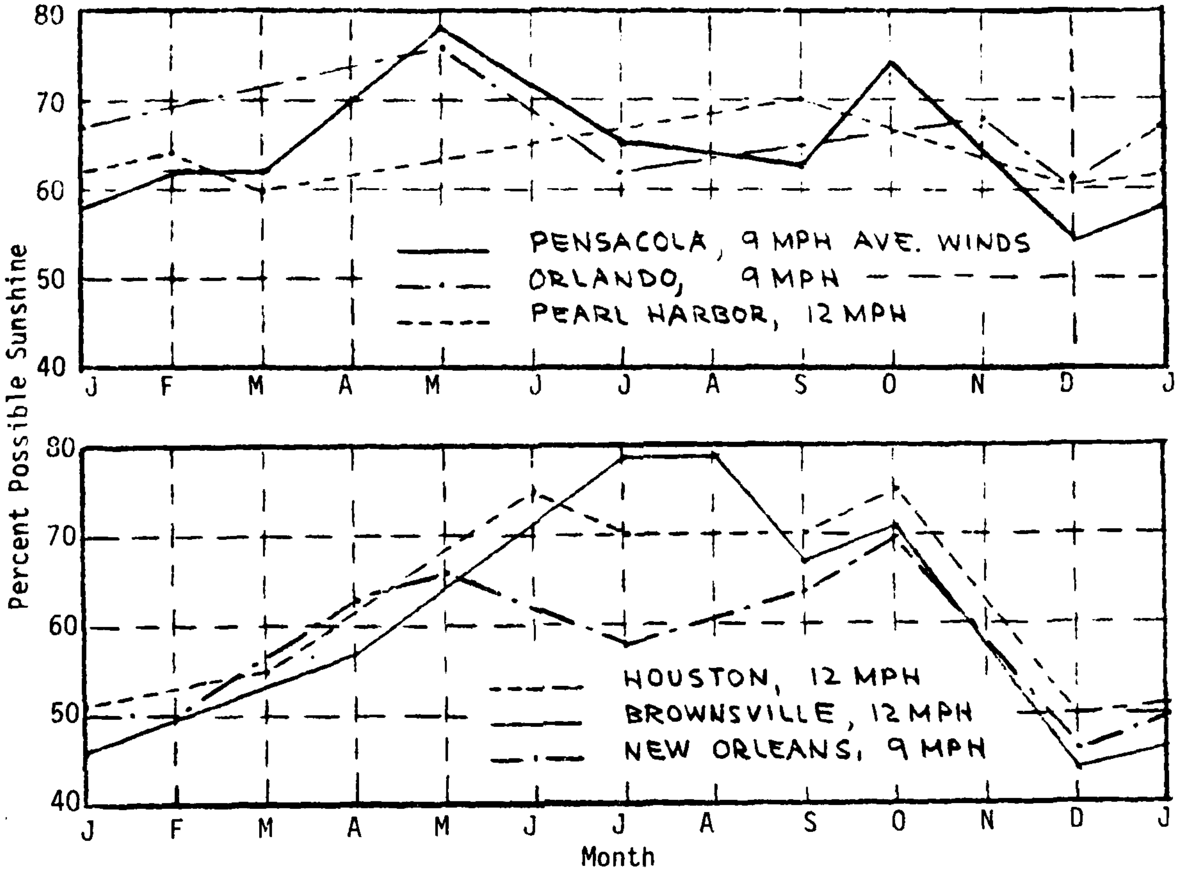



Figure 5.1 Mean Percent Sunshine Possible in Warm, Humid U.S. Climatic Regions (averaged from data in Reference [13]).

multiplied by an additional 0.90 to account for the reduced efficiency of the storage. Using excessive amounts of storage is not advisable in these climates because this would either reduce the efficiency of the auxiliary heating system or increase summer discomfort. Additional studies will need to be made to obtain more accurate estimates of performance.

If the design incorporates an exposed greenhouse, a series of separate calculations for the greenhouse alone should be made, using Worksheets 1 through 5. The monthly heat loss of the greenhouse is subtracted from the monthly solar heat absorbed and multiplied by a factor of 0.8 if the heat distribution is easily made with large openings (windows, vents with fans, etc.). If the heat distribution is more indirect, (i.e. storage wall only) the heat gain must be reduced by a factor of 0.5 for each month. (These factors are only estimates and will need to be checked against operational data; however, they do represent a reasonable adjustment for the reduced efficiency; the resulting overall auxiliary load figures should be within the accuracy of the other input data and operating conditions, considering the large possible yearly and daily variation in the weather.) Worksheet 5A can be used to compute the adjusted net solar greenhouse heat gain.

The effect of a roof overhang can be calculated with the tables given in the following section. If the home will have an off-south (skew) orientation, mid-winter solar heat gain will also be reduced, as indicated in Section 5.3. Warm climates require that SW, SE, S and W-facing walls and windows be carefully shaded with vegetation, vertical grilles, wide covered porches etc. -- without blocking the summer breeze.

Table 5.1
Effectiveness Factors

(to adjust heat gain from different solar mechanism to the application of a single estimator curve)

Multiply the gross window collector area by a frame shading factor of 0.80 to 0.95 depending on construction (for solar roofs and roof ponds, use the unshaded (projected) horizontal roof area instead) and by one of the following:

| | |
|---|---|
| 0.85 | for double-glazed direct-gain windows with regular glass |
| 0.90 | for double-glazed direct-gain windows with low-iron glass |
| 1.00 | for single-glazed direct-gain windows with regular glass |
| 1.05 | for single-glazed direct-gain windows with low-iron glass |
| 0.70 | for double-glazed vented uninsulated Trombe walls* |
| 0.65 | for double-glazed unvented uninsulated Trombe walls |
| 0.80 | for double-glazed vented Trombe walls with R-9 night insulation* |
| 0.75 | for double-glazed unvented Trombe walls with R-9 night insulation |
| 1.05 | for double-glazed water walls with R-9 night insulation* |
| 1.10 | for single-glazed water walls with R-9 night insulation* |
| 0.50 | for well-insulated roof ponds |
| 0.075 | for dark-colored shingle or metal solar roofs |
| 0.04 | for medium-colored built-up solar roofs |

*With optimum wall thickness of 10 to 16 inches and thermal storage of about 0.45 Btu/°F-$ft^2$ [7]

WORKSHEET 5

CALCULATION OF SOLAR HEATING CONTRIBUTION

Mechanism: ______________________________

Net Effective Collector Area: ____________ $ft^2 = A_{eff}$

$A_{eff} = A_{gross}$ x (Frame Shading) x (Effectiveness, Table 5.1)

| Month | Solar Heat Gain from Figures 5.2 & 5.3 Btu/Month-$ft^2 \times 10^3$ (1) | Adjustment Factors: Roof Overhang from Worksheet 5B (2) | Adjustment Factors: Off South Orientation: % Reduction from Sec. 5.3 (3) | Solar Heat Absorbed in MBtu/month $A_{eff}$ x (1) x (2) x (3) |
|---|---|---|---|---|
| Aug. | | | | |
| Sept | | | | |
| Oct. | | | | |
| Nov. | | | | |
| Dec. | | | | |
| Jan. | | | | |
| Feb. | | | | |
| Mar. | | | | |
| Apr. | | | | |
| May | | | | |
| Jun. | | | | |
| Jul. | | | | |

WORKSHEET 5A

ADJUSTED NET SOLAR GREENHOUSE HEAT GAIN

| Month | Solar Heat Gain Absorbed (from Worksheet 5 of Greenhouse Calculations) | | Monthly Heat Loss (Net Thermal Load) from Worksheet 4 * MBtu/month | | Net Heat Gain MBtu/month x Adjustment Factor ( ) | = | Adjusted Net Solar Greenhouse Heat Gain |
|---|---|---|---|---|---|---|---|
| Aug. | ____________ | - | ____________ | = | ____________ | | ____________ |
| Sept. | | | | | | | |
| Oct. | | | | | | | |
| Nov. | | | | | | | |
| Dec. | | | | | | | |
| Jan. | | | | | | | |
| Feb. | | | | | | | |
| Mar. | | | | | | | |
| Apr. | | | | | | | |
| May | | | | | | | |
| Jun. | | | | | | | |
| Jul. | | | | | | | |

*For greenhouse heat loss to the outside only.

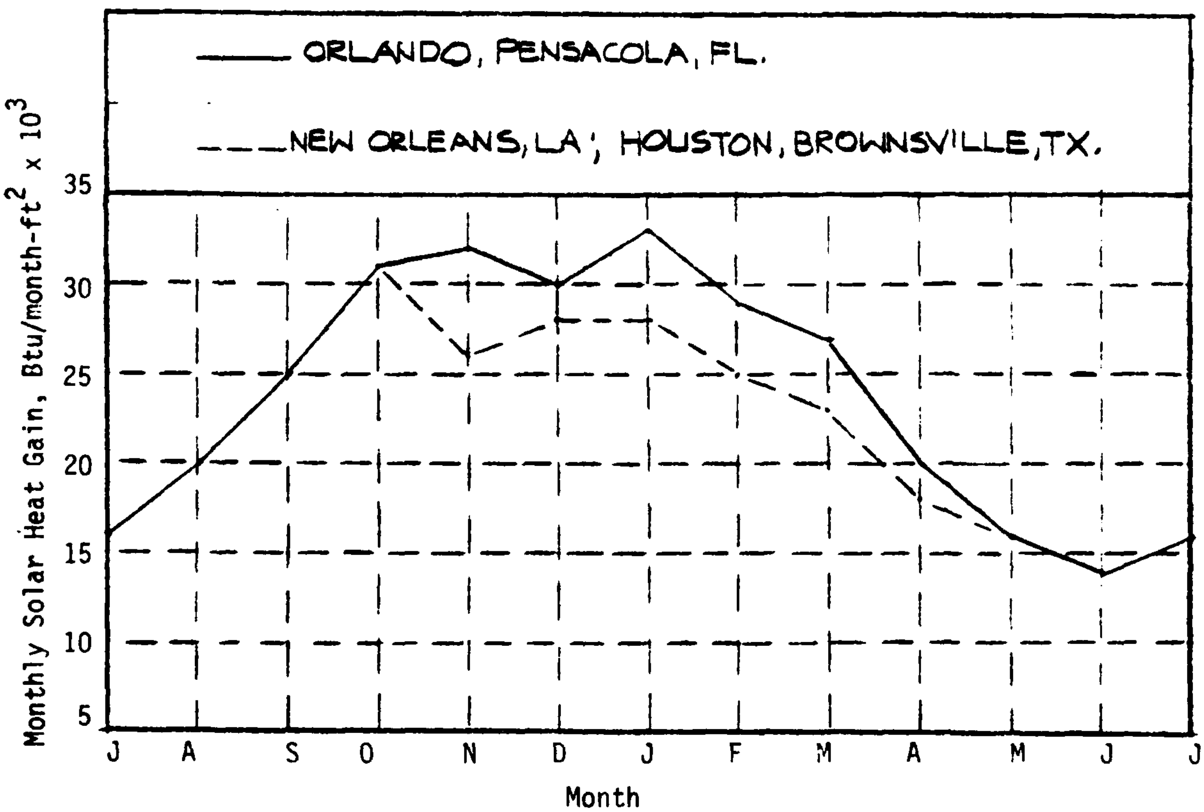



Figure 5.2 Monthly Average Solar Heat Gain Through Vertical South-Facing Single Glazing

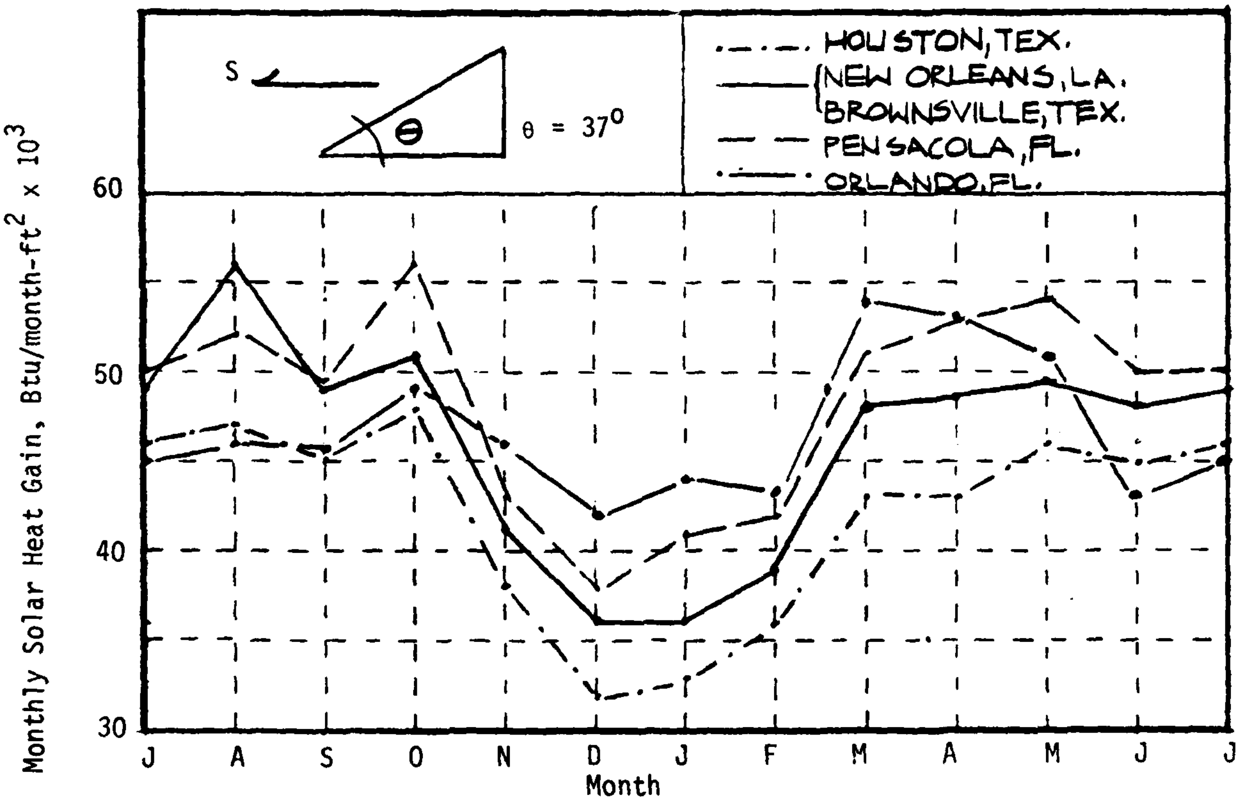



Figure 5.3 Monthly Average Solar Radiation Striking South-Facing Surface at 37° Tilt

### 5.2 Calculations and Adjustments for Roof Overhang

In case a roof overhang is used on the south side to give summer shading, the vertical length of the shadow cast in relation to the length of the horizontal roof projection is given in Table 5.2 for the different latitudes of warm, humid Navy locations.

Once the overhang dimension has been tentatively decided on, it will have to be checked for winter shading by using Worksheet 5B. Table 5.3 lists the vertical length of the shadow cast per foot of roof overhang projection for different latitudes. When multiplied by the size of the overhang, the length of the shadow cast at noon is obtained and entered in Column (I). For example, at 28° N latitude, a 2 ft overhang would cast a 6.8 ft shadow in April. This illustrates how important it is to keep overhangs to a minimum in colder climates where solar heating is required into the late spring. Spring shading on south-facing vertical surfaces from a roof overhang can reduce heat gain to such an extent that more auxiliary heat will be required than in mid-winter. However, in warm climates, the overhang must be sized to prevent solar heat gain from mid-March through early November.

Shading of the window should be checked for each heating month by calculating the shadow length. If much shading occurs, the solar heat gain from Figure 5.2 used on Worksheet 5 must be reduced for those months (or the overhang should be of a folding or removable type). Since the shadow is given for the noon hour when it is at its maximum, it is not necessary to take its full effect into account; about two-thirds will give a better approximation over the whole day. Note that the values in Table 5.2 are only valid for south orientation. The shading factor (reduction in solar heat gain) in Column (M) of Worksheet 5B is entered in Column 2 of Worksheet 5.

TABLE 5.2

Summer Shading with Roof Overhang

| Latitude (A) | | Length (ft) of Horizontal Projection to Cast Shadow on South Wall from 11 April - 1 September | | | |
|---|---|---|---|---|---|
| | (B) | 4 ft Shadow | 6 ft Shadow | 8 ft Shadow | 10 ft Shadow |
| 24° N Lat | (C) | 1.1 | 1.7 | 2.2 | 2.8 |
| 28° N Lat | | 1.4 | 2.1 | 2.8 | 3.5 |
| 32° N Lat | | 1.7 | 2.5 | 3.4 | 4.2 |

TABLE 5.3

Winter Shading With Roof Overhang at Noon

(South Orientation)

| (H) Height of Shadow Cast for Latitude per Foot of Projecting Overhang, ft | | | |
|---|---|---|---|
| Month | 24° N Latitude | 28° N Latitude | 32° N Latitude |
| S | 2.2 | 1.9 | 1.6 |
| O | 1.4 | 1.2 | 1.1 |
| N | 1.0 | 0.9 | 0.8 |
| D | 0.9 | 0.8 | 0.7 |
| J | 1.0 | 0.9 | 0.8 |
| F | 1.4 | 1.2 | 1.1 |
| M | 2.2 | 1.9 | 1.6 |
| A | 4.5 | 3.4 | 2.7 |
| M | 13.0 | 7.0 | 4.5 |
| J | | 12.0 | 6.5 |

WORKSHEET 5B

CALCULATION OF SHADING WITH SOUTH ROOF OVERHANG

(A) Latitude of building site: _____ °N

(B) Length of summer shadow desired: _______ ft

(C) Size of roof overhang (projection from south wall) from Table 5.2 (directly or interpolated): ___________ ft

(D) Height of lower overhang edge from finished floor: ____________ ft

(E) Distance from finished floor to top of glazing: __________ ft

(F) Vertical distance from top of glazing to roof overhang:

(D) - (E) = __________ ft

(G) Window or glazing height: _________ ft**

| Month | Height of Shadow Cast, ft (H) x (C) = (I) | Effective Shadow Length, ft (J) = 2/3 (I) | Window Shading, ft* (K) = (J) - (F) | % Shading, (K)/(G) = (L) | Shading Factor, (M) = 1 - (L) |
|---|---|---|---|---|---|
| S | | | | | |
| O | | | | | |
| N | | | | | |
| D | | | | | |
| J | | | | | |
| F | | | | | |
| M | | | | | |
| A | | | | | |
| M | | | | | |
| J | | | | | |

Enter Column (M) in Column 2, Worksheet 5.

* If (J) - (F) is less than zero, enter zero in Column (K).

** If window (glazing) height varies, a reasonable average can be assumed.

## 5.3 Influence of Off-South Orientation

In retrofit applications, the heat-gaining surfaces and glazing will not always be facing true south or nearly so. Figure 5.4 gives the percent of solar radiation striking a vertical wall, with the true south exposure receiving the monthly maximum or 100 percent (for 24°N and 32°N latitude). A linear interpolation may be made for other latitudes within this range. Note that deviations of ±30° receive from 80 to 85 percent of the mid-winter radiation in these latitudes; this percentage drops to around 70 for the SE and SW orientation and to about 30 for E, W orientations. The percent reduction (or increase) is read from Figure 5.5 and entered in Column 3, Worksheet 5 in decimal form (i.e. 60% = 0.60). A slightly eastern orientation may be desirable where early morning heat gain is wanted and possible with climatic and topological conditions (i.e. no pattern of early morning fog or mountains to the east) and where the summer breeze is predominantly from an easterly direction. Because of the large heat gains on E and W facing walls in southern latitudes, an off-south orientation can pose a more difficult problem in the summer. Special attention will have to be paid to shading these surfaces in the summer without impeding natural ventilation. Roof overhangs are not useful in orientations more than about 20° off south, because they would have to be extremely large to be effective.

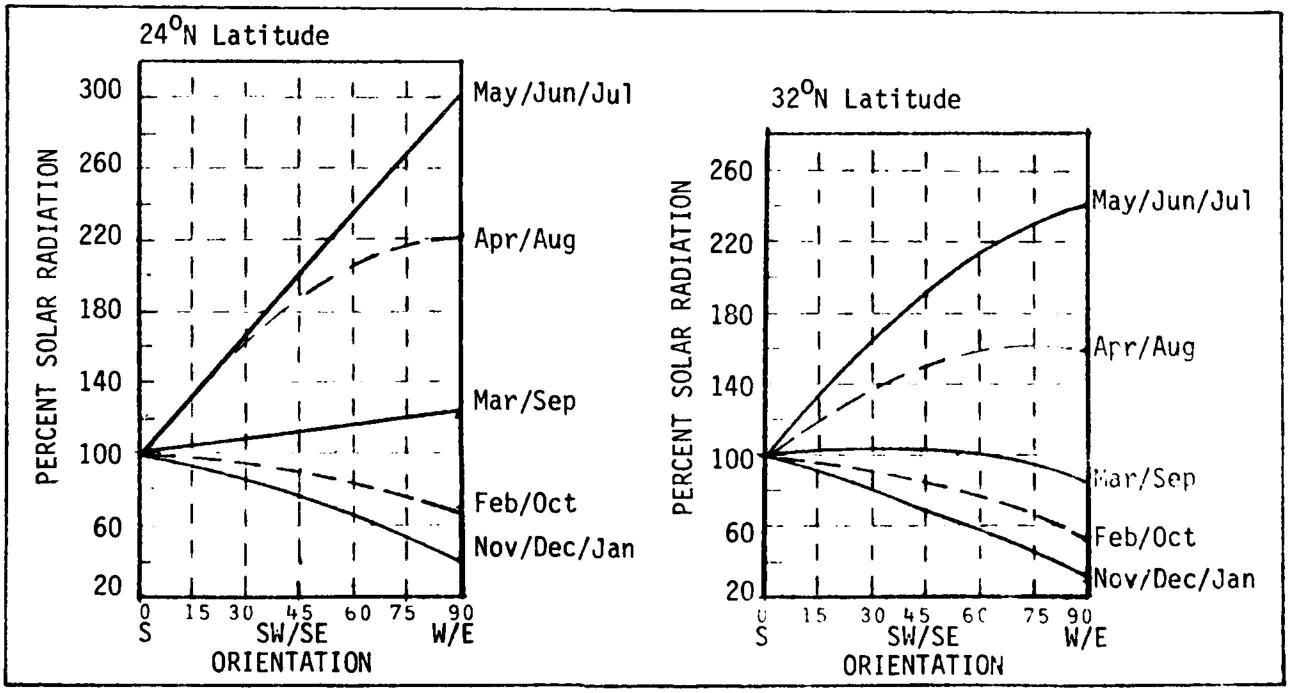


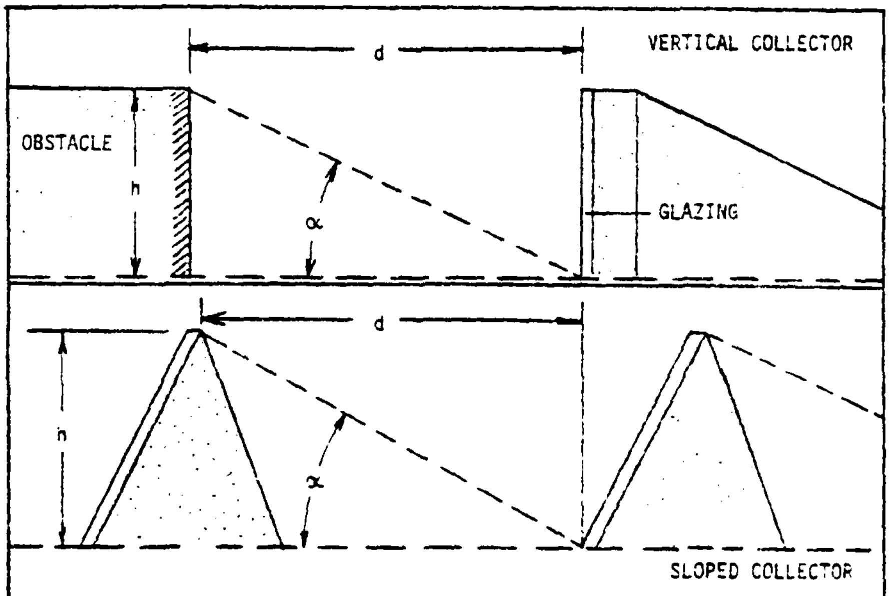

Figure 5.4 Percent of Maximum Solar Radiation Received on Vertical Walls Deviating from True South at 24° and 32° N Latitude (Ref. [6])

## 5.4 Spacing for Sawtooth Clearstory Window Arrangements

If south-facing clearstory windows and/or solar collectors for water heating are arranged in more than one row, the spacing between these rows must be large enough to avoid shading the second row by the first row. The formula below can be used to calculate the length of the shadow for any obstacle that may be in front of the solar glazing, be it collector or window. For comparatively narrow obstructions, the solar altitude value at noon should be used; for shading by longer rows, a value earlier in the morning should be chosen. The formula for the spacing distance is:

$$d = h/\tan\alpha$$

where d, h and $\alpha$ are defined in Figure 5.5. The obstacle height can be taken off the design drawings. The sun altitude angles $\alpha$ for December (the worst




h = height of front row of collectors, sawtooth roof section or any other obstacle

d = distance between obstacle and nearest point of second-row glazing

α = solar altitude angle

Figure 5.5 Definition of Symbols Used in Sawtooth Spacing Calculation condition) for southern latitudes and different times of day are listed in Table 5.4, together with the corresponding values for tan $\alpha$.

For example, if the obstacle height of a long row is 6 feet, the spacing to the second-row glazing should be $d = 6/\tan 23^{\circ} = 6/0.42 = 14.3$ ft for a building in Corpus Christi, Texas, with no shading after 9 a.m. If this spacing is too large for the design under consideration, a compromise is called for. Some shading after 9 a.m. may have to be tolerated or the clearstory windows or collectors can be raised some in the second row. If no shading after 10 a.m. would be an acceptable compromise, the spacing distance would be reduced to $d = 6/\tan 31^{\circ} = 6/0.60 = 10.0$ ft. Since this calculation was made for the month of December, any other time of the year will have less shading on the second row even very early in the morning.

TABLE 5.4

Sun Altitude Angles on 21 December for Southern Latitudes and Different Times of Day, together with the Function tan $\alpha$

| Solar Time | 24°N Lat | | 28°N Lat | | 32°N Lat | |
|---|---|---|---|---|---|---|
| | $\alpha$ | tan $\alpha$ | $\alpha$ | tan $\alpha$ | $\alpha$ | tan $\alpha$ |
| 7 a.m. | 3° | 0.05 | 0° | -- | 0° | -- |
| 8 a.m. | 15° | 0.27 | 13° | 0.23 | 10° | 0.18 |
| 9 a.m. | 25.5° | 0.48 | 23° | 0.42 | 20° | 0.36 |
| 10 a.m. | 34° | 0.67 | 31° | 0.60 | 28° | 0.53 |
| 11 a.m. | 40° | 0.84 | 36.5° | 0.74 | 33° | 0.65 |
| Noon | 42.5° | 0.92 | 38.5° | 0.80 | 34.5° | 0.69 |

### 5.5 Calculation of Building Auxiliary Load Profile

Worksheet 6 is used to determine the solar load ratio and ultimately the auxiliary load profile. Values for the net thermal load are transferred from Worksheet 4. The total solar heat gain for each month is the sum of all passive/ hybrid absorbed solar heat figures from Worksheets 5 and the adjusted net heat gain from Worksheet 5A in the case of a greenhouse. The solar load ratio (SLR) is the total monthly solar heat gain divided by the monthly net thermal load. The solar heating fraction (SHF) is then obtained from the solar heating estimator (Figure 5.6) for the corresponding value of solar load ratio for each month. The monthly solar heating contribution is obtained by multiplying the SHF with the net thermal load. Finally, the auxiliary load profile is calculated by subtracting the solar heating contribution from the net thermal load.

Depending on the size of the house and its location, an auxiliary monthly load of 1 to 2 MBtu can easily be supplied with an efficient wood burner. Economically, it is probably not necessary to supply more than a solar heating fraction of about 0.7 in the mid-winter months since the solar heat gain needed to increase the fraction above 70 percent is proportionally much larger than at lower SHF, and the added investment is most likely neither cost-effective nor necessary, since too much heat gain during the coldest months will lead to increased likelihood of overheating, especially in the fall. More importantly even, the calculated auxiliary load will occur only in the coldest years, because it is impossible to accurately take the "comfort factor" into account in these calculations. However, from experience it has been found that passively-heated homes usually feel comfortable at much lower interior air temperatures than do conventionally heated houses; thus less auxiliary heat will be needed in the actual case than is indicated by the calculations, especially for designs that incorporate some type of zoning where bedrooms would remain unheated when the auxiliary is used, and for designs which have a considerable amount of thermal mass (where justified by climatic conditions).

It is very important in locations with cool winters to choose the auxiliary wood burner (References [14, 15]) or other backup system with great care. If a conventional system is used, it must be sized correctly for the small loads of these well-insulated houses. Reference [4] contains a discussion of auxiliary heating in New Mexico; much of the discussion also applies to conditions elsewhere. The future availability of the auxiliary energy source must be considered. Wind generators may be attractive and economical in locations with strong, steady winds.

WORKSHEET 6

CALCULATION OF BUILDING AUXILIARY LOAD PROFILE

| Month | Net Thermal Load (from Worksheet 4) (A) | Total Solar Heat Gain (from Worksheet 5) (B) | Solar Load Ratio (SLR) (B) ÷ (A) (C) | Solar Heating Fraction (SHF) (from Fig. 5.6) (D) | Solar Heating Contrib. (D) x (A) (E) | Auxiliary Load Profile (A) - (E) (F) |
|---|---|---|---|---|---|---|
| Aug. | | | | | | |
| Sept. | | | | | | |
| Oct. | | | | | | |
| Nov. | | | | | | |
| Dec. | | | | | | |
| Jan. | | | | | | |
| Feb. | | | | | | |
| Mar. | | | | | | |
| Apr. | | | | | | |
| May | | | | | | |
| Jun. | | | | | | |
| Jul. | | | | | | |
| TOTAL | MBtu | | | | MBtu | MBtu |

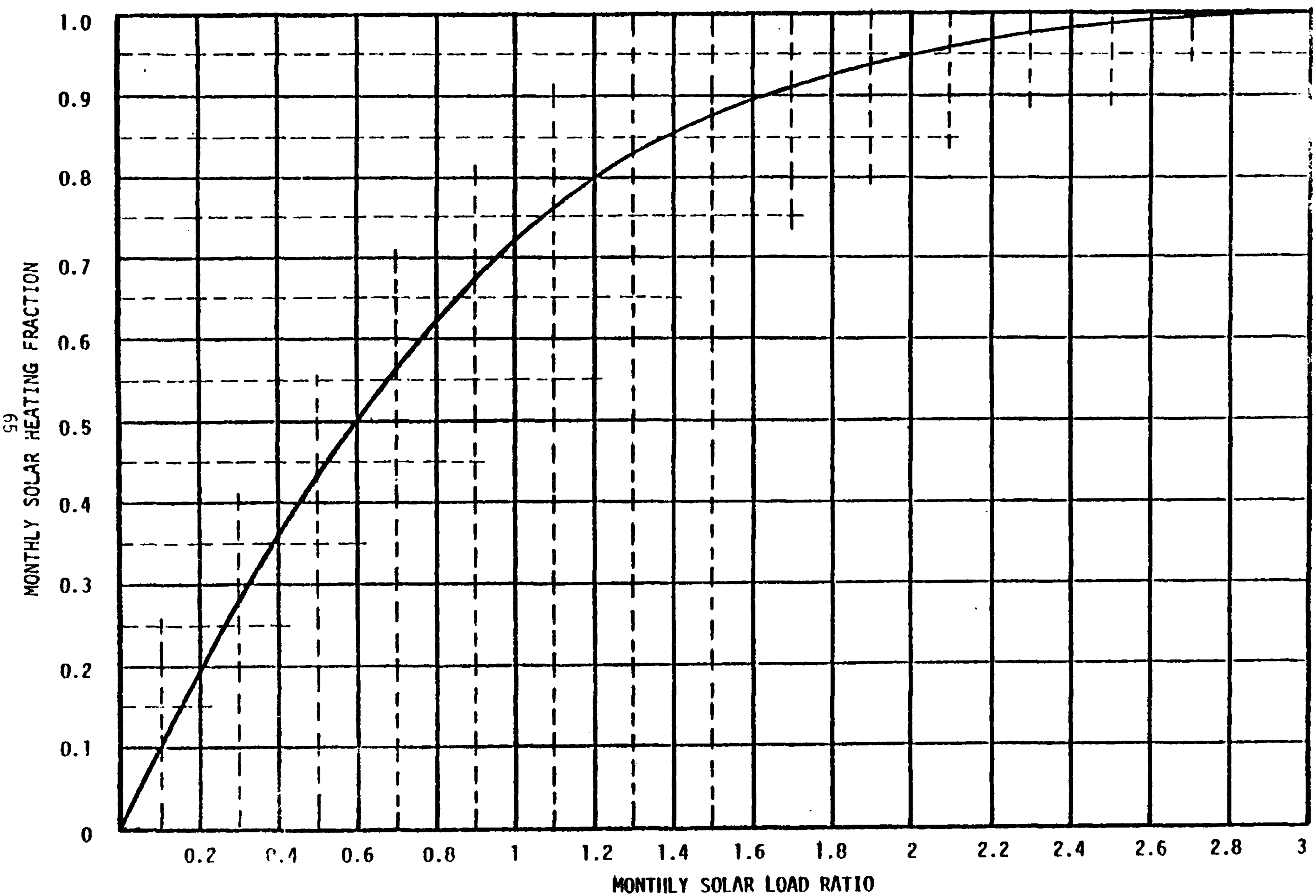



Figure 5.6 Monthly Passive Solar Heating Estimator

## 6. GLAZING AND STORAGE CALCULATIONS

A very rough estimate of the ratio of south-facing window area to floor area for direct gain houses is given by the following:

For cold climate, glass area/floor area = 0.2 - 0.3
For moderate climate, glass area/floor area = 0.15 - 0.25
For warm climate, glass area/floor area = 0.1 - 0.15

These values are given for houses with maximum insulation, adequate mass, good heat distribution and small auxiliary heaters. Approximately the same relationship should also hold for each solar-heated space or room; however, the location of each room and its use must be taken into consideration. For instance, kitchens with many internal heat sources will need less solar heat than living areas, and sleeping areas used only at night may also remain cooler. Reference [1] gives many additional rules of thumb for glazing and storage sizing.

The importance of good heat distribution together with an adequate amount of mass for the specific climatic conditions cannot be overemphasized. For example, south-facing rooms should not be too small and should have large door openings as well as masonry walls connecting to the north-side rooms, if they are not open areas altogether. The storage mass should have a large surface area (with a thickness from 6 to 18 inches for masonry) well distributed over the rooms. It does not have to be in direct sunlight, although the effectiveness of direct gain is increased (and less mass is required) if at least a portion of the heat storage mass receives direct sun in the mid-winter months during a good part of the day.

The amount of storage mass will determine the comfort in the house, i.e. the daily temperature swing that will be experienced and the heat loss over a completely cloudy day. Table 6.1 gives a tabulation of storage mass required per temperature swing of the storage mass and the maximum solar heat gain per day for 100 square feet of south-facing windows. For masonry walls that are not directly exposed to the sun, a temperature rise of around $5^{o}F$ would be comfortable; for mass exposed to the sun, a temperature rise of $20^{o}$-$25^{o}F$ is not unusual. For a combination, a $\Delta T$ of $10^{o}F$ maximum is a good value to be assumed for the calculations and design. In warm, humid climates, storage mass must not be overdesigned, and it should be placed in full sun if possible to reduce the volume.

Worksheet 7 can be used to tabulate these calculations for each room. Note that the storage volume will have to be adjusted for the actual glazing in each room (net area of glass), since it is listed in Table 6.1 on the basis of a 100 square foot window area. To calculate the maximum temperature drop in the house for an average January day without any solar gain or auxiliary heating, the formula in the lower half of Worksheet 7 can be used. Values for heat capacity of storage materials are listed in Table 6.2. A calculated drop of $8^{o}F$ or less is considered to be adequate for a direct-gain house in a sunny climate. A much larger drop indicates that some auxiliary heating will be required on most cloudy days. Actual performance will be better than the calculations indicate in many cases, since nights during cloudy periods have higher average temperatures than clear nights, and also because some solar radiation is received even during cloudy conditions. For a second, consecutive day, the temperature drop would be somewhat less, because this type of heat loss follows an exponential curve.

For fully exposed south-facing vertical double glazed windows at $28^{o}N$ latitude, the maximum clear-day daily heat gain in December/January is about 1500 Btu/ft$^2$-day. To calculate an adequate amount of storage, determine the daily solar heat gain per square foot for the design, then choose a value for $\Delta T$ and read the volume of storage required from Table 6.1. This value must be adjusted for the room by multiplying by the south window area of the room and dividing by 100. More mass than this will give a lower $\Delta T$. If only a small amount of space is available, water exposed to the sun directly behind the glazing will use the least volume; if space is not critical, mass walls can be used; they will supply support, ease of maintenance and soundproofing. Phase-change materials (eutectic salts) may be available commercially in the future for heat storage that will be able to store large amounts of heat in a small volume (Reference [2]). These would be especially suitable for warm, humid locations.

When the design of the home has been completed, the storage mass in the building should be checked once more. If the mass is scanty (especially in areas with many clear days in the winter), the daily temperature levels in the home will fluctuate wildly; if the mass is too large (especially in areas with many cloudy days in the winter), it will be difficult to warm up the home again after a long period of cloudy weather, and too much auxiliary heat will be diverted to recharging the storage. It will not be economical to spend money on excessive storage. In houses where solar is not expected to supply nearly the entire daily net heat load (that is, some auxiliary heating is acceptable for most days), storage can be somewhat higher; it will be useful for load management and to avoid rapid cooling in areas where supply interruptions of the auxiliary fuel are likely.

Completing Worksheets 1 through 7 with the data from the preliminary design sketches should give the designer a good idea of the expected performance of the planned passive solar building* and the influence of the different design components and their relationships. The procedure should be repeated each time changes are made and finally with the exact dimensions off the finalized blueprints and building specifications. Window dimensions especially seem to change at the last minute depending on what is available at the local supplier at a good price or in order to comply with codes when getting the building permit. The U-value of the wall and roof materials and insulation finally chosen may also vary from that assumed for the design calculations, depending on market conditions, especially if last-minute substitutions have to be made because of shortages or in a more fortunate case because an unexpected bargain becomes available. Calculations should be redone if the U-values of walls and/or roof are higher than those used in the calculations, to check if additional solar heat should be provided. On the other hand, if the U-values are considerably lower than those used in the calculations, it may be possible to reduce solar window size or relax some other design specifications as compensation. Since the heat loss of the building is very much influenced by the R-factor of window night insulation and since this component will be one of the last to be chosen and installed, adjustments can be made here if heat losses have changed because of substitutions which have arisen during the building phase.

---

*If actual operating conditions (i.e. infiltration rate) will closely correspond to the assumptions made in the calculations.

WORKSHEET 7

GLAZING AND STORAGE CALCULATIONS

Daily Maximum Solar Heat Gain:________

| Room | South Glazing $ft^2$ | Floor Area $ft^2$ | Designed Storage $ft^3$ | Storage Volume per 100 $ft^2$ of Glazing $ft^3$ | Temp. Swing °F |
|---|---|---|---|---|---|
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| TOTAL | | | | | |

Check for temperature drop during a completely cloudy day (24-hour period):

$$\text{Maximum } \Delta T = \frac{\text{Net January Thermal Load*/31}}{\text{Total Volume x (Heat Capacity of Storage Material)**}}$$

$$\Delta T = \frac{(\qquad)}{31\,(\qquad)\,(\qquad\qquad)} = \underline{\qquad\qquad}\ ^{\circ}F$$

*From Worksheet 4.
**From Table 6.1.

Table 6.1

Mass Required to Store Solar Heat Gain Through Windows

| Maximum Daily Solar Heat Gain Btu/ft²-day | Temperature Swing of Thermal Mass ΔT, °F | Volume of Storage per 100 sq. ft of Window Area: Water ft³ | Water gal. | Concrete ft³ |
|---|---|---|---|---|
| 500 | 5 | 160 | 1200 | 415 |
| | 10 | 80 | 600 | 210 |
| | 15 | 55 | 400 | 140 |
| | 20 | 40 | 300 | 105 |
| | 25 | 30 | 225 | 85 |
| 750 | 5 | 240 | 1800 | 625 |
| | 10 | 120 | 900 | 315 |
| | 15 | 30 | 600 | 210 |
| | 20 | 60 | 450 | 155 |
| | 25 | 50 | 375 | 115 |
| 1000 | 5 | 320 | 2400 | 830 |
| | 10 | 160 | 1200 | 420 |
| | 15 | 110 | 825 | 280 |
| | 20 | 80 | 600 | 210 |
| | 25 | 60 | 450 | 170 |
| 1250 | 5 | 400 | 3000 | 1050 |
| | 10 | 200 | 1500 | 520 |
| | 15 | 130 | 1000 | 350 |
| | 20 | 100 | 750 | 260 |
| | 25 | 80 | 600 | 210 |
| 1375 | 5 | 440 | 3300 | 1150 |
| | 10 | 220 | 1650 | 585 |
| | 15 | 145 | 1100 | 385 |
| | 20 | 110 | 825 | 285 |
| | 25 | 90 | 675 | 230 |
| 1500 | 5 | 480 | 3600 | 1250 |
| | 10 | 240 | 1800 | 630 |
| | 15 | 160 | 1200 | 420 |
| | 20 | 120 | 900 | 310 |
| | 25 | 100 | 750 | 250 |
| 1750 | 5 | 560 | 4200 | 1460 |
| | 10 | 280 | 2100 | 730 |
| | 15 | 190 | 1425 | 490 |
| | 20 | 140 | 1050 | 360 |
| | 25 | 110 | 825 | 290 |

TABLE 6.2

Heat Transfer Characteristics of Masonry Storage Materials Compared to Water, Wood and Steel

| Material | Specific Heat Btu/lb-°F | Density lb/ft$^3$ | Heat Capacity Btu/ft$^3$-°F | Conductivity $\frac{\text{Btu-in.}}{\text{hr-°F-ft}^2}$ |
|---|---|---|---|---|
| Adobe | 0.22 | 90-105 | 20-23 | 4 |
| Brick | 0.21 | 110-130 | 23-27 | 5 |
| Brick with magnesium additive | 0.2 | 120 | 24 | 26 |
| Concrete (Stone, Sand) | 0.16 | 140 | 22 | 12 |
| Concrete (Cinder Block) | -- | 80 | -- | 2.5 |
| Gravel (30% voids) | 0.21 | 115 | 24 | 2.6 |
| Earth | 0.21 | 95 | 20 | 6 |
| Pumice | -- | 49 | -- | 1.3 |
| Sand | 0.2 | 100 | 20 | 2 |
| Stone | 0.2 | 165 | 33 | 11-12 |
| Steel | 0.12 | 490 | 59 | 310 |
| Wood | 0.6 | 30 | 18 | 0.8-1.1 |
| Water | 1.0 | 62.4 | 62.4 | 4 |

## 7. ENERGY SAVINGS CALCULATIONS

Since many people are not only interested in knowing how much auxiliary energy will need to be expended to heat the designed building, but also in how much energy is saved (in order to calculate the cost-effectiveness of the passive method), a brief discussion of the topic is included here. Unfortunately, the problem is rather complex, since results depend on the performance calculation method used [16] and on the design of a "reference" building. Since a passive design is a combination of very good insulation, sufficient storage mass and correct choice and placement of heat-gaining windows, walls, roofs and spaces, it is very difficult to determine what the conditions would have been for a "similar" building but without passive heating. Would such a building still have the same shape, orientation, roof line, volume, size, floor plan, etc., since these were to a very large extent chosen with passive heat gain in mind? Thus, for the sake of simplicity and uniformity, it is proposed here that the minimum U-values for the building's design be used as specified in the local building code. Also assumed are a standard ceiling height of 8 feet unless the reference building would definitely have been designed with a different ceiling height. A square floor plan with windows 10 percent of the floor area and distributed equally in all four directions is assumed also, if the passive solar building has a rectangular shape. If the passive house has a more complicated floor plan, the same shape should be assumed for the reference building but with windows distributed equally in all 4 directions. The main reason for these assumptions is that up to now buildings on the whole have been oriented with complete disregard to solar gains, so that on an average, just as many windows and building orientations are found in each direction.

Worksheet 8A can then be completed in a manner similar to the calculation procedure for passive houses, though the computations are somewhat simplified. The same values for heating degree days and solar heat gain should be used as in the passive computations. Internal heat gain is not subtracted in conventional houses, since it is assumed that this heat will help raise room temperatures from the 65$^{\circ}$F design temperature to a more comfortable 70$^{\circ}$F or so, in contrast to many passive solar homes which are quite comfortable at 65$^{\circ}$F air temperature. Effective window area for south-window solar gain is calculated in the same way as for the passive design and then multiplied by one half, since some of these windows may be shaded. The auxiliary load of the solar design from Worksheet 6 can then be compared with the heating load of the reference building.

On Worksheet 8B, the heating load of the reference building from Worksheet 8A is listed first. Subtracted from this is the auxiliary load of the passive design, as calculated on Worksheet 6. This will give the heat saved in MBtu by using the passive design. If the passive design uses fans and other motorized equipment, these power requirements will have to be subtracted from the gross heat saved to get a true picture of the real savings between the two buildings. This power usage is usually obtainable in kWh; for conversion to MBtu, it must be multiplied by 0.0034 before it is listed on Worksheet 8B.

The energy savings depend on the fuel that is being replaced by solar. Energy savings can be calculated for the most commonly available energy source in the area or for all of them. The results of course will only reflect savings based on the current price of these fuels. Solar energy is neither subject to price escalation nor inflation once the equipment is installed or the structure is built. With the steep increases in the cost of fossil fuels, the savings due to solar can be expected to increase dramatically if considered over the life of the structure (which can be as much as 50 years or more for a well-built house). In order to express the cost per unit energy in dollars per million Btu, the cost is multiplied with a conversion factor (which also includes a multiplier for efficiency).

For example, if electricity were to heat the reference building, the cost in cents/kWh is multiplied by 2.93 to get the cost in $/MBtu (since 1 MBtu = 293.1 kWh) and by the net energy saved to get the total monthly savings in dollars.

If gas is assumed to be the fuel for heating the reference building, the net heat saved is multiplied with the cost of gas ($/MCF) times 1.7 to take burner efficiency into account. Natural gas is sold in units of one thousand cubic feet (or MCF) which have a heat content of around 1 MBtu. At present, most utilities have a sliding price scale for their energy sales; this means that large users pay less per unit than do small users. Thus it may be somewhat difficult to obtain exact quotes for gas prices per MCF for these calculations. The situation is somewhat similar for electricity costs also. If you have recent utility bills at hand, you may calculate an average price

WORKSHEET 8A

CALCULATIONS FOR REFERENCE BUILDING

Building Location: Zone:

Floor Area: _____ $ft^2$ = ( _____ $ft)^2$; Perimeter = _____ ft;

S. Window Area = (0.1)(A)÷4 = _______ $ft^2$;

Effective Area = ½( )( )( ) = _____ $ft^2$

Building Skin Conductance (Btu/hr-°F):

Total Wall and Window Combination: U-Value x Area = ( )x( )= _____
Roof: U-Value x Area = ( )x( )= _____
Floor (R= _____ ): F x Perimeter: (see Table 7-2) = ( )x( )= _____

TOTAL $\boxed{\quad}$

Infiltration: Volume x $C_p$ x ACH = ( ) x ( ) x 1 = $\boxed{\quad}$

Modified Building Heat Loss Coefficient $C_B$

= 24 (Skin Conductance + Infiltration) = 24[( + )] = $\boxed{\quad}$

$C_B/A$ = $\boxed{\quad}$ Btu/D.D.-$ft^2$

Heat Load Calculations(MBtu): Gross Heating Load minus Solar Heat Absorbed is equal to Net Heating Load

| Month | Degree Days | Gross Heating Load | Solar Gain | Solar Heat Absorbed | Net Heating Load |
|---|---|---|---|---|---|
| Aug. | | | | | |
| Sept. | | | | | |
| Oct. | | | | | |
| Nov. | | | | | |
| Dec. | | | | | |
| Jan. | | | | | |
| Feb. | | | | | |
| Mar. | | | | | |
| Apr. | | | | | |
| May | | | | | |
| Jun. | | | | | |
| Jul. | | | | | |

WORKSHEET 8B

HEAT SAVINGS CALCULATIONS FOR PASSIVE DESIGN*

| Month | Reference Bldg. Heating Load | Passive Solar Building Aux. Load | Gross Heat Saved | Parasitic Power (See Footnote), kWh x 0.0034 | Net Energy Saved | Cost of Energy Saved: ELECTRICITY: cents/kWh x 2.93 GAS: $/MCF x 1.7 ** OIL: $/gal x 14.4 *** WOOD: $/cord x 0.11 **** =____ $/MBtu x Net Savings = | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MBtu/mo. | MBtu/mo. | MBtu | MBtu | MBtu | $ | | | |
| | | | | | | EL | GAS | OIL | WOOD |
| Aug. | ( ) - | ( ) = | | | | | | | |
| Sept. | | | | | | | | | |
| Oct. | | | | | | | | | |
| Nov. | | | | | | | | | |
| Dec. | | | | | | | | | |
| Jan. | | | | | | | | | |
| Feb. | | | | | | | | | |
| Mar. | | | | | | | | | |
| Apr. | | | | | | | | | |
| May | | | | | | | | | |
| Jun. | | | | | | | | | |
| Jul. | | | | | | | | | |
| TOTAL | | | | | | | | | |

*Does not include savings for solar water heating (or summer cooling).

**60% efficiency.

*** 1 MBtu = 7.2 gal. heating oil, 50% efficiency.

****Average of 20 MBtu per cord of wood depending on type [15] and 45% efficiency.

Add electricity needed to run the conventional furnace; substract the electricity needed to operate fans in the passive design.

from these. Do not forget to include taxes and any charges for fuel cost adjustments included on the bill. The last column in Worksheet 8B then represents the savings in an average heating season with present energy prices. At present, gas prices in many areas are still relatively low (and the savings correspondingly small); this situation, however, can change rather quickly once natural gas prices become deregulated. Electricity is expensive, because it is a secondary energy source which has been generated from a primary source (gas, oil, hydro, wind, nuclear, coal etc.). This conversion, when using fossil fuels, is only about 30% efficient. Electricity is also a high-temperature, high-quality energy source, and its use for heating is in most cases not appropriate, unless it is generated from a renewable source such as a wind machine and its supply is abundant and reliable.

In this warm, humid climate, the major energy savings will come from passive cooling methods (since they will reduce or replace expensive electricity used for refrigerated air conditioning). In a carefully designed home, these savings should be at least 70% of the cooling costs of an equivalent conventional structure and can approach almost 100% if the refrigerated air conditioner can be eliminated altogether by passive techniques. Solar water heating can easily supply about 75% of the domestic hot water load if designed, sized and installed correctly.

Since energy prices are expected to double in another ten years or less, it can be seen that the savings will increase in future years to make the passive design even more worthwhile. To this, add the benefit of a healthier environment (inside and outside the house and in the community), possibly less maintenance and less noise because of the mass, a longer life for the building because of its quality construction, and federal* and state** solar tax rebates, and it can be seen that even with somewhat higher construction costs the well-designed and well-built passive building will be an excellent

*Federal legislation now in Congress may soon allow tax rebates for the passive components of a building.

**State solar tax rebates vary from state to state. Some counties and municipalities may also have special benefits for solar construction, i.e., exemptions from sales tax, property tax, etc.

investment indeed. The passive house will also be (and feel) so much warmer, especially since people in conventional homes are turning their thermostats down to save energy and money.

If you have difficulties with this calculation procedure, it may be helpful if you could attend a solar workshop which is held periodically in different cities around New Mexico; these workshops are sponsored and taught by the New Mexico Solar Energy Institute in cooperation with the New Mexico Solar Energy Association (NMSEA). If your design incorporates a Trombe wall or greenhouse, attending a hands-on workshop conducted by the New Mexico Solar Energy Association in Santa Fe or its affiliated local societies is highly recommended, or similar workshops may be held by solar societies in your area. A completed set of worksheets is attached in the Appendix, giving the calculations for a sunspace passive solar home in Corpus Christi, Texas (800 H.D.D.).

NOTES:

## REFERENCES


1. E. Mazria, The Passive Solar Energy Book, Rodale Press, Emmaus, PA, 1979.

2. P. F. Kando, "Eutectic Salts," Solar Age, Vol. 3, No. 4, April 1978, pp. 15-16, 40.

3. Jeffrey Cook, Cool Homes for Desert Suburbs, Arizona Solar Energy Commission, 1700 W. Washington, Phoenix, Arizona 85007, June 1979.

4. Monika Lumsdaine, Passive Solar House Designs for New Mexico Climates, Part I, Design Manual, NMEI Rpt. 22-1, New Mexico Solar Energy Institute, New Mexico State University, Las Cruces, NM 88003, 1980.

5. Randy Sweat, "Natural Cooling Techniques - An Overview," Southwest Bulletin, New Mexico Solar Energy Association, Vol. 5, No. 3, March 1980, pp. 6-8.

6. ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers), Handbook of Fundamentals, 1972 (or later, revised editions).

7. J. Douglas Balcomb and R. D. McFarland, "A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Type," Proceedings of the 2nd National Passive Solar Conference, American Section of ISES, Philadelphia, PA, 16-18 March 1978, Vol. II, pp. 377-389.

8. Bruce Anderson, Solar Energy Housing Design in Four Climates, Total Environmental Action, Harrisville, NH, 1975.

9. W. J. Van der Meer, "Effective U Values," NMEI Report #76-161A, University of New Mexico, July 1977.

10. SOLARON Application Engineering Manual, Solaron Corporation, 720 S. Colorado Blvd., Denver, CO 80222, October 1978.

11. V. Cinquemani, et al., Input Data for Solar Systems, National Climatic Center, Asheville, NC, November 1978 [prepared for D.O.E. under Agreement No. E(49-26)-1041].

12. T. Kusuda and K. Ishii, "Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States and Canada," NBS Building Science Series 96, U. S. Dept. of Commerce, National Bureau of Standards, April 1977.

13. Climatic Atlas of the United States, U.S. Department of Commerce, June 1968.

14. The Woodburners Encyclopedia, Vermont Crossroads Press, Waitsfield, Vermont 05673, 1976.

15. Mary Twitchell, Wood Energy, Garden Way Publishing, Charlotte, Vermont 05445, 1978.

16. L. Palmiter and B. Hamilton, "A Comparison of Performance Factors for Passive Solar Heating," Southwest Bulletin, New Mexico Solar Energy Association, Vol. 4, No. 1, January/February 1979, pp. 18-22.

## ADDITIONAL RECOMMENDED READING


17. Rick Fisher and Bill Yanda, Solar Greenhouse, John Muir Publications, Santa Fe, NM 87501, 1976.

18. D. A. Bainbridge, "Water Wall Passive System - For New and Retrofit Construction," Proceeding of the 3rd National Passive Solar Conference, American Section of ISES, San Jose, CA, 11-13 January 1979, pp. 473-478.

19. Stephen Weinstein, Architectural Concerns in Solar System Installations, Prepared for the Department of Energy under Contract No. E-77-C-01-2522; available from National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, Virginia 22161 (Solar/0801-79/01, Distribution Category UC-59).

20. James L. Easterly, Engineering Concerns in Solar System Design and Operation, prepared for the Department of Energy under Contract No. EG-77-C-01-2522; available from National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161 (Solar 0511-79/01, Distribution Category UC-59).

21. Franklin Research Center, Installation Guidelines for Solar DHW Systems in One- and Two-Family Dwellings, Contract H-2377, Report HUD-DR-407, Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402, April 1979.

22. Sunset Books, Homeowner's Guide to Solar Heating, Lane Publishers, Menlo Park, California, 1978.

23. Bruce Anderson and Michael Riordan, The Solar House Book, Chesire Books, Harrisville, New Hampshire, 1976.

24. Bruce Anderson, Solar Energy: Fundamentals in Building Design, McGraw-Hill, New York, 1977.

25. D. Wright, Natural Solar Architecture, Van Nostrand Reinhold Co., New York, 1978.

26. A Survey of Passive Solar Buildings, AIA Research Corporation, Stock No. 023-000-00437-2, Superintendent of Documents, Government Printing Office, Washington, DC, 20402, $3.75, February 1978.

27. In The Bank---or Up the Chimney, Abt Associates, Inc.; Stock No. 023-000-00411-9, Superintendent of Documents, U. S. Government Printing Office, Washington, DC, 20402, 1977, $1.70. (Information on insulation.)

28. William A. Shurcliff, New Inventions in Low-Cost Solar Heating (100 Daring Schemes Tried and Untried), Brick House Publishing Company, Harrisville, NH, 03450, 1979.

29. Dan Scully, Don Prowler, Bruce Anderson, The Fuel Savers, A Kit of Solar Ideas for Existing Homes, Brick House Publishing Company, Harrisville, NH 03450, 1978.

30. Norah D. Davis and Linda Lindsey, At Home in the Sun, Garden Way Publishing, Charlotte, Vermont, 05445 (paperback), 1979. (This book is about solar home living experience, including performance and cost.)

31. William A. Shurcliff, Thermal Shutters and Shades: Over 100 Schemes for Reducing Heat Loss Through Windows, Brick House Publishing Co., Inc., Andover, Mass., 1980.

32. Passive Solar Design Handbook, Vol. 1 (Bruce Anderson): Passive Solar Design Concepts; Vol. 2 (Doug Balcomb, et al.): Passive Solar Design Analysis, DOE/CS-0127 US 59, 1980. Available from National Technical Information Services, U.S. Dept. of Commerce, 5285 Port Royal Rd., Springfield, Virginia, 22161. Cost: $13.25 for Vol. 1, $14.00 for Vol. II.

33. William A. Shurcliff, Superinsulated and Double Envelope Houses: A Preliminary Survey of Principles and Practice, 1980; Available from the author, 19 Appleton Street, Cambridge, Mass., 02138, $10 (payment enclosed), $12 (billed).

## ADDITIONAL SOURCES OF INFORMATION

National Solar Heating and Cooling Information Center — toll free
P. O. Box 1607, Rockville, MD 20850 — 1-800-523-2929

(U.S.) Solar Energy Research Institute (SERI)
1536 Cole Boulevard
Golden, CO 80401
(D.O.E. - funded research)

Solar Lobby — (202) 466-6350
1001 Connecticut Avenue, NW, 5th floor
Washington, DC 20036
(polictical action group concerned with solar legislation at the federal level)

Florida Solar Energy Center
300 State Road 401
Cape Canaveral, Florida 32920 — (305) 783-0300

Solar Age Magazine, Solar Productes Specifications Guide, Solar Vision Inc., Harrisville, NH, 03450; 6 updates per year, $100.

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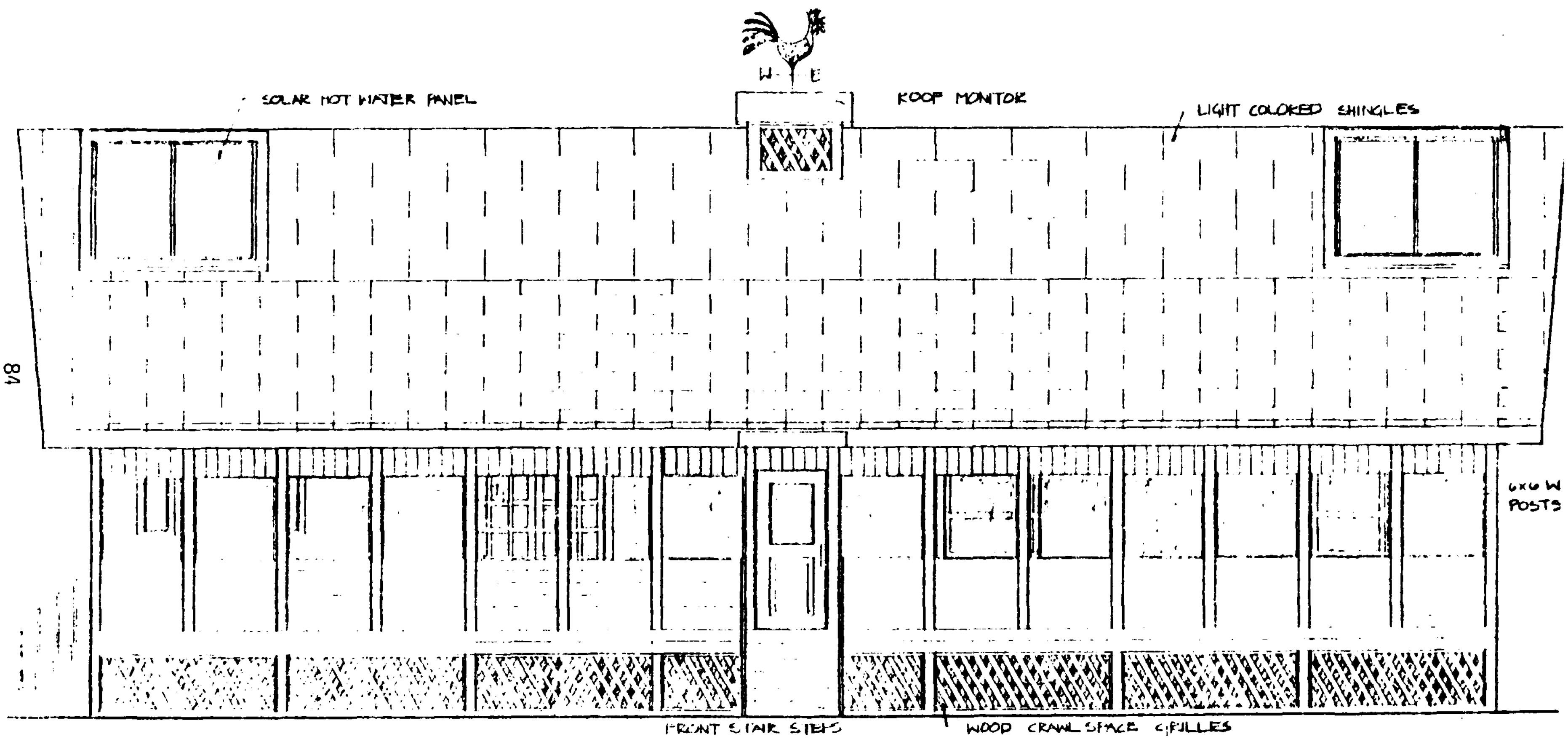
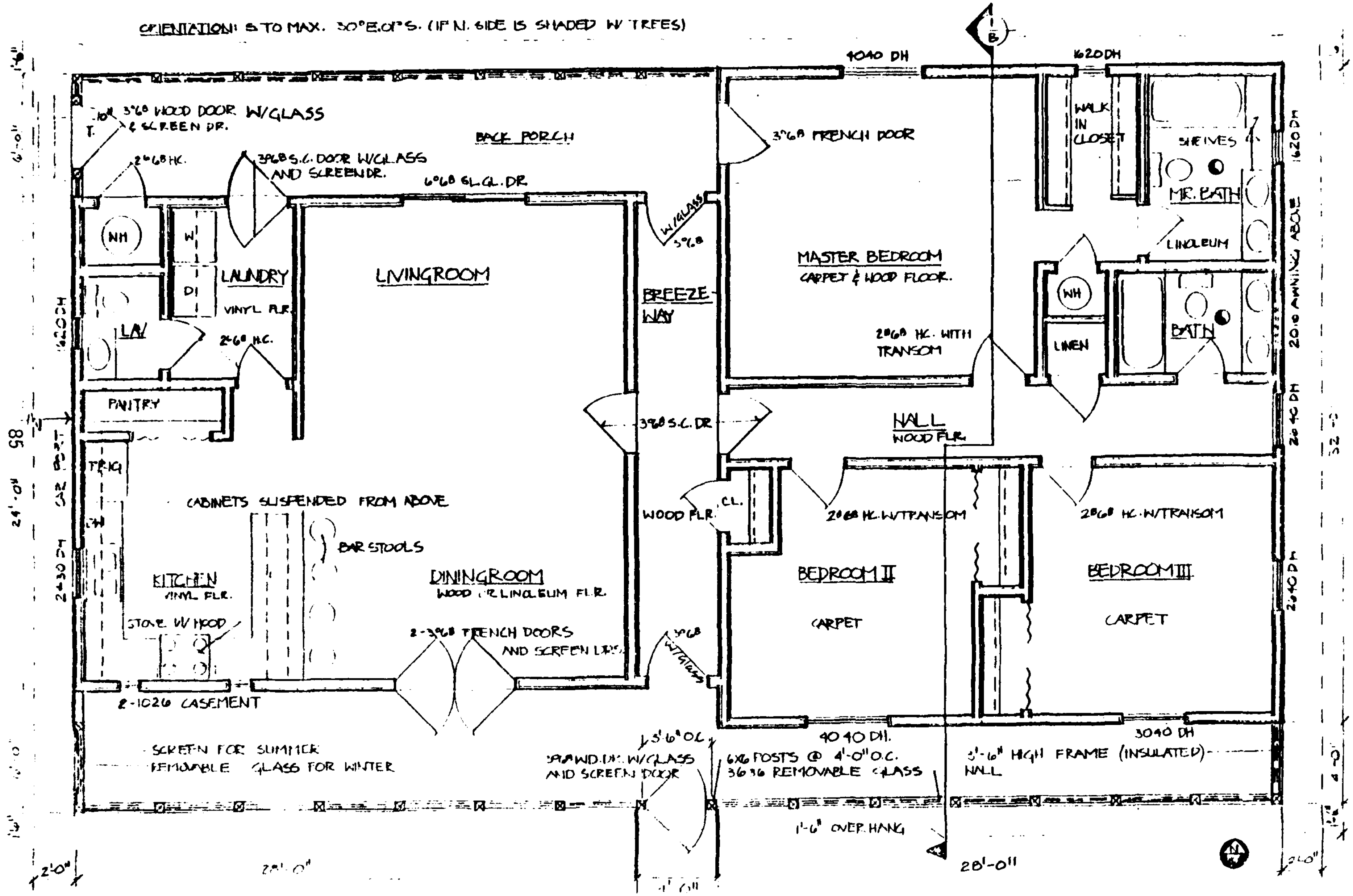
# APPENDIX

## DESIGN AND CALCULATION EXAMPLE FOR WARM, HUMID CLIMATE



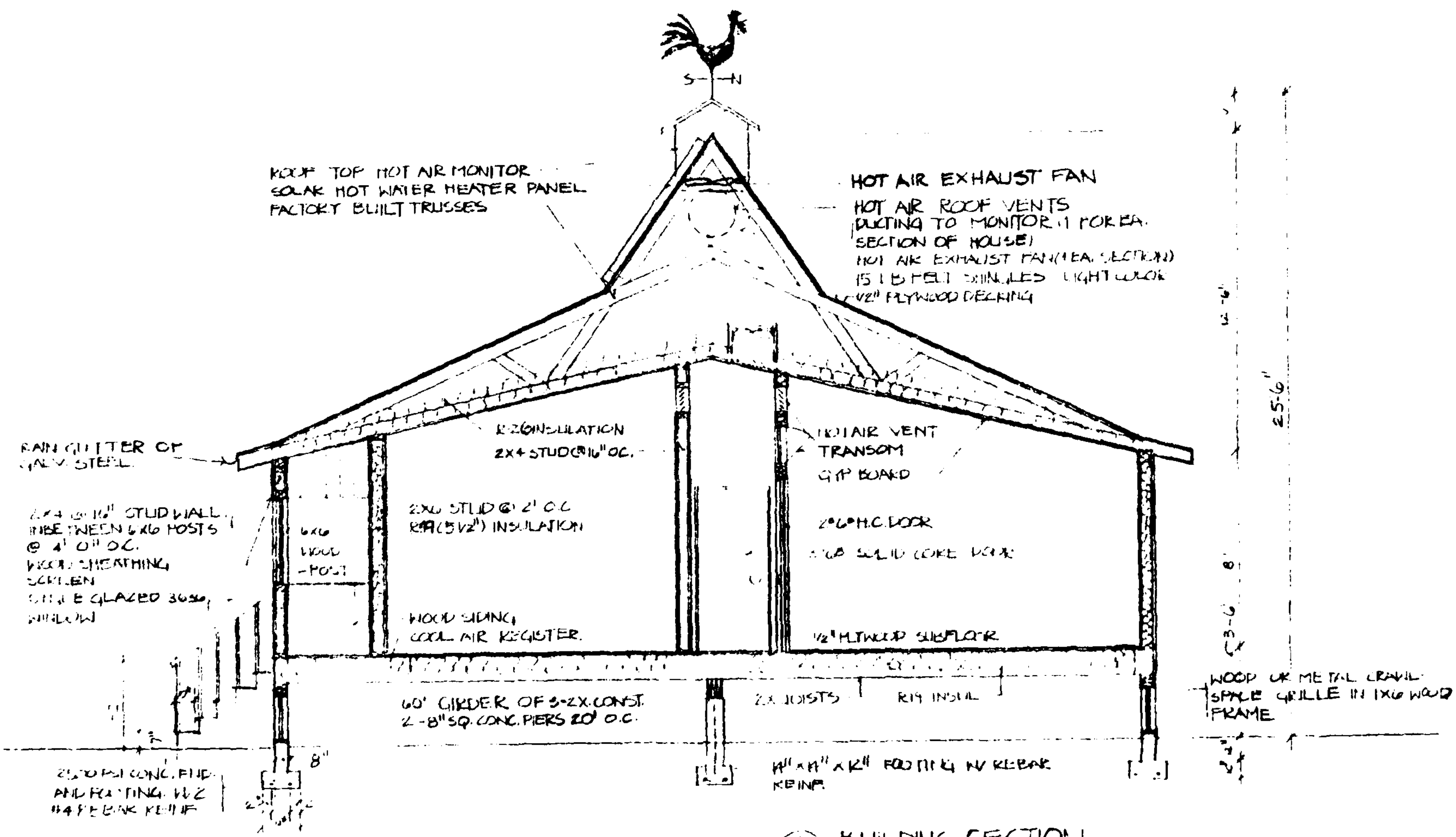

SOUTH ELEVATION

CASA LEONA




FLOOR PLAN
CASA LEONA

DRW. BY MA CHASE 5-80




BUILDING SECTION

CASA LEONA

METHOD I

WORKSHEET 1A

DESIGN INFORMATION

CASA LEONA

1. Location of building: CORPUS CHRISTI Altitude: SEA LEVEL
2. Building type (one or two story, split-level, etc.): 1 STORY
3. Roof shape: MODIFIED GABLE
4. Lot size: 100' x 120' Special features: Summer breeze must not be obstructed; space for trees needed.
5. Lot orientation (in which direction will the house face the street?): S to 30°E
6. Building setbacks (check with local codes):
7. Zoning restrictions and covenants:
8. Lot access: SOUTH OR WEST
9. Utility access:
10. Lot slope, water runoff (erosion?), berming: GOOD DRAINING AWAY FROM HOUSE IS ESSENTIAL
11. Predominant direction of winter wind: SSE Velocity: 12 mph average
12. Predominant direction of summer breeze: SE Velocity: 12 mph average
13. Direction of best view:
14. Direction of worst view:
15. Shading from neighboring houses, trees, etc.: Desirable except in winter on South porch.
16. Approximate floor area: 1570 Heated basement? NO
17. Number of occupants:
18. Number of bedrooms, baths: 3 BEDROOMS, 2 1/2 BATHS
19. Other living spaces wanted:
20. Life style of occupants and special needs (i.e. play area for children, space for entertaining, hobbies; space used during day, evening; special storage requirements; handicaps): WELL VENTED, OPEN LIVING SPACES, SEPERATE BR WING; SUNSPACE IN WINTER (FOR PLANTS)
21. Preferred patio location, other outdoor recreation areas: SCREENED IN NORTH AND SOUTH PORCHES.
22. Occupants like the following features:
23. Occupants dislike the following features:

METHOD I

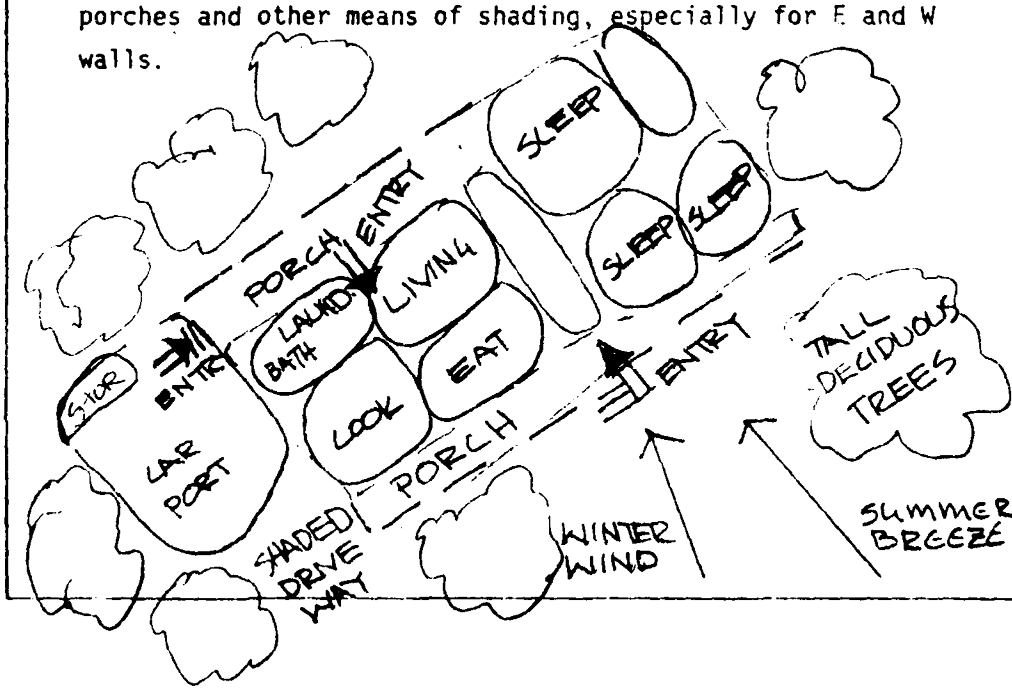
WORKSHEET 18

SPACE RELATIONSHP DIAGRAM

CASA LEONA

Floor area: APPROX 1600 sq. ft.

Sketch the location of the main entry and the living, cooking, eating and sleeping areas; then mark the major wind directions and place kitchen, baths, utility, and laundry rooms downwind of the prevailing summer breeze. Use storage areas and garage/carport as buffer zones against winter winds and summer heat. Indicate the zoning barrier (■ ■ ■) and tentatively mark the location of auxiliary wood burners (✳) (if any). Areas thus marked will need to be designed so that they can be completed closed off from the remaining sections of the house during periods when auxiliary heating is necessary. Finally, show the direction(s) of the best view (and, optionally, undersirable views which will need to be screened). Indicate roof overhangs, porches and other means of shading, especially for E and W walls.



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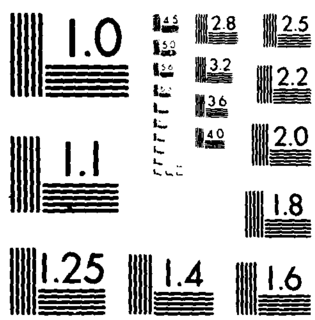



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

METHOD I

WORKSHEET 1C

ADDITIONAL INFORMATION AND CHECKLIST FOR ENERGY CONSERVATION

CASA LEONA

| | |
|---|---|
| ✓ | Building orientation is primarily broadside to prevailing summer breeze YES POSITIONED UP TO 20° E. OF S. |
| ✓ | Windbreaks are provided against winter storms. ON SOUTH, E+W |
| ✓ | Windows are of double-glazed casement or double-hung type? YES<br>Window areas to the north, east and west are minimized. |
| ✓ | E and W walls are completely shaded in the summer. |
| ✓ | Windows allow sufficient natural summer ventilation. |
| ✓ | Windows are insulated at night by (insulated drapes, shades, louvers, interior or exterior shutters): WINDOW QUILT, SHUTTERS |
| ✓ | Can such shutters be used as hurricane protection if necessary? YES |
| ✓ | Passive solar mechanisms included in the design are: SOUTH FACING GLASS FOR PORCH IN WINTER |
| | Storage mass is located at: |
| ✓ | Are fans used for heat distribution or cooling?: YES Where? LIVING ROOM / DINING ROOM + BEDROOM SECTION HALL. |
| ✓ | Is there a solar greenhouse? SOUTH FACING GLASS IN WINTER |
| ✓ | Will plants in the house be away from direct sun? IN SUMMER PUT |
| ✓ | Can humidity in the house be easily vented? VENTS (FANS) IN LR/DR |
| ✓ | Is the main entry an air lock in the winter? YES |
| ✓ | What type backup space heater is planned? ELECTRIC RADIATOR IN MR. BRM. |
| ✓ | Will a solar water heater be used? YES What type? |
| ✓ | Solar tank location, size: 80 GAL. |
| ✓ | Collector location: ROOF Type: Area needed: 20 ft²/person |
| | Heat exchanger(s): |
| ✓ | Collector slope (approximately equal to latitude +10° is best): 38° |
| ✓ | Backup water heater, type, size, fuel: ELECT. IN MR. BR. |
| ✓ | Is the water heater isolated from the living space? YES. |
| ✓ | Energy-efficient applicances to be used are: STOVE, MICROWAVE DISHWASHER, REFRIGERATORS, STOVE HOOD. |
| ✓ | Fluorescent lights are to be used in: KITCHEN, LAUNDRY, BATHROOM. |
| | Wood burner or stove? Output: Btu/hr |
| | |

METHOD I

WORKSHEET 1D

BUILDING DIMENSIONS
(for Worksheet 2)

CASA LEONA

| Orientation/ Type | Gross Wall Area, ft$^2$ | Window Area, ft$^2$ | Door Area, ft$^2$ | Net Wall Area, ft$^2$ | Perimeter ft |
|---|---|---|---|---|---|
| | ( ) - [( | )+( | )] = ( | ). | ( ) |
| Total NW LIV. | 32×9 = 288 | | -80 | 208 | |
| Total N SLEEP | 28×8 = 224 | -19 | | 205 | |
| Total NE | | | | | |
| Total E | 32×10 = 320 | -26 | | 294 | |
| Total SE | | | | | |
| Total W | 32×10 = 320 | -10 | -20 | 290 | |
| Total SW | | | | | |
| Total S E sun porch | 4×8.5 = 34 | -12 | | 22 | |
| Total S W sun porch | 60×8 = 480 | -172 | -20 | 288 | |
| Total Trombe | 6×8.5 = 51 | -12 | | 39 | |
| Total ~~Air Lock~~ | 565 | 196 | 20 | 349 | |
| Total | ( 1152 ) - [( | 55 )+( | 100 )] = ( | 997 ). | ( ) |
| Roof | Gross Roof Area ( 2030 ) - | Skylights ( ) = | | Net Roof Area ( 2030 ) | |

METHOD I

WORKSHEET 2

CALCULATION OF BUILDING SKIN CONDUCTANCE

CASA LEONA

| Surface Type | Net Area $ft^2$ | | U-value $Btu/hr\text{-}°F\text{-}ft^2$ | | U x Area Btu/hr-°F* | % of Total |
|---|---|---|---|---|---|---|
| North exterior wall | 413 | X | | = | | |
| East exterior wall | 294 | X | (0.051) | = | 51 | |
| West exterior wall | 290 | X | | = | | |
| South exterior wall | | X | | = | | |
| South T~~rombe wall~~ sun-porch | 350 | X | (0.09) | = | 32 | |
| ~~Air lock walls~~ | | X | | = | | |
| Total Wall Heat Loss | | | | | $\boxed{83}$ | 15% |
| Doors: Entry | | X | | = | | |
| Patio | 100 | X | 0.49 | = | 49 | |
| Other | | X | | = | | |
| North windows | 19 | X | | = | | |
| East windows | 26 | X | 0.35 | = | 19 | |
| West windows | 10 | X | | = | | |
| ~~South windows~~ Sunporch | 196 | X | 1.13 | = | 221 | |
| Clerestory windows | | X | | = | | |
| Sloped skylights | | X | | = | | |
| Horizontal skylights | | X | | = | | |
| Total Door/Window Heat Loss | | | | | $\boxed{289}$ | 53% |
| Roof R-26 | 2030 | X | 0.039 | = | $\boxed{80}$ | 14% |
| Floor ** R-19 vented | 1968 | X | 0.05 | = | $\boxed{98}$ | 18% |
| Total Building Skin Conductance (add boxed-in values) | | | | | 550 | 100 |

* The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

** Crawlspace = $Ah_c$ (see Figure 4.1) OR U x A (if vented in Winter)

Slab = F x P (see Table 4.1)

Heated basement = $UA_{\text{wall above grade}} + h_b A_{\text{wall below grade}} + h_c A_{\text{floor}}$

METHOD I

WORKSHEET 3

CALCULATION OF INFILTRATION LOAD AND
MODIFIED BUILDING HEAT LOSS COEFFICIENT $C_B$

CASA LEONA

House Volume = Gross Floor Area x Ceiling Height =( 1968 )( 10 )= 19700

Infiltration Load = Volume x $C_p$ x ACH          ACH = Air Change/Hour

= (19700) x (0.018) x (0.5 )

= 177 Btu/hr-°F

Modified Building Heat Loss Coefficient, $C_B$

= [Building Skin Conductance* + Infiltration Load]

= 24 [( 550 ) + ( 177 )] = 24 ( 727 )

= 17,500 Btu/D.D.

Gross Heated Floor Area of Building = 1970 $ft^2$

$C_B$/A = (17,500) / ( 1970 )

= 8.5 Btu/$ft^2$-D.D.          D.D. = Degree Days**

* From Worksheet 2.

**"Degree Days" is an indication of the "coldness" of the climate for heating calculations; the degree-day value for a particular day is the difference between the average daily outdoor temperature and 65°F; the data is usually given in monthly and yearly totals. Averaged degree-day data for New Mexico is listed in Table 1-1.

METHOD I

## WORKSHEET 4

## CALCULATION OF BUILDING THERMAL LOAD PROFILE

CASA LEONA

Modified Building Heat Loss Coefficient $C_B$ from Worksheet 3 = 17,500 Btu/D.D.

| Month | Degree Days per Month | $\times C_B$ | = | Gross Thermal Load, MBtu/month | – | Internal Heat Sources, MBtu/month | = | Net Thermal Load, MBtu/month |
|---|---|---|---|---|---|---|---|---|
| Aug. | ____ | $\times C_B$ | = | ____ | – | ____ | = | ____ |
| Sept. | ____ | $\times C_B$ | = | ____ | – | ____ | = | ____ |
| Oct. | | | | | | | | |
| Nov. | 80 | | | 1.4 | | 1.0 | | 0.4 |
| Dec. | 200 | | | 3.5 | | 1.0 | | 2.5 |
| Jan. | 230 | | | 4.0 | | 1.0 | | 3.0 |
| Feb. | 170 | | | 3.0 | | 1.0 | | 2.0 |
| Mar. | 120 | | | 2.1 | | 1.0 | | 1.0 |
| Apr. | 800 | | | 14.0 | | | | 9.0 |
| May | | | | | | | | |
| Jun. | | | | | | | | |
| Jul. | | | | | | | | |

2 adults, 12 hrs/day = 300,000 BTU
2 children, 12 hrs/day = 150,000 Btu
Appliances + lights = 900,000 Btu
water heater = 100,000 Btu
Laundry = 50,000 Btu
1.5 MBtu (2/3)

MBtu = Million Btu

METHOD I

WORKSHEET 5

CALCULATION OF SOLAR HEATING CONTRIBUTION

Mechanism: DIRECT GAIN 172 (0.9) = 155

Net Effective Collector Area: ____________ $ft^2 = A_{eff}$

$A_{eff} = A_{gross} \times$ (Frame Shading) x (Effectiveness, Table 5.1)

CASA LEONA

| Month | Figures 5.2-5.3<br>Solar Heat Gain from ~~Tables 5.2 - 5.4~~ Btu/Month-$ft^2 \times 10^3$ (1) | Adjustment Factors<br>Roof Overhang from Worksheet 5B (2) | <br>Off South Orientation: % Reduction from Sec. 5.3 (3) | Solar Heat Absorbed in MBtu/month $A_{eff} \times (1) \times (2) \times (3)$ |
|---|---|---|---|---|
| Aug. | | | 20° E of S | |
| Sept | | | | |
| Oct. | | | | |
| Nov. | 26 | 1.0 | 0.9 | 3.6 |
| Dec. | 28 | 1.0 | 0.9 | 3.9 |
| Jan. | 28 | 1.0 | 0.9 | 3.9 |
| Feb. | 25 | 1.0 | 0.95 | 3.7 |
| Mar. | 23 | 1.0 | 1.05 | 3.0 |
| Apr. | | | | |
| May | | | | |
| Jun. | | | | |
| Jul. | | | | |

METHOD I

WORKSHEET 5B

CALCULATION OF SHADING WITH SOUTH ROOF OVERHANG

CASA LEONA

(A) Latitude of building site: 28 °N

(B) Length of summer shadow desired: _______ ft

(C) Size of roof overhang (projection from south wall)
from Table 5.2 (directly or interpolated): 1.5 ft

(D) Height of lower overhang edge from finished floor: 7.5 ft

(E) Distance from finished floor to top of glazing: 6'4" ft

(F) Vertical distance from top of glazing to roof overhang:
(D) - (E) = 1'-2" ft

(G) Window or glazing height: 3'-6" ft**

| Month | Height of Shadow Cast, ft (H) x (C) = (I) | Effective Shadow Length, ft (J) = 2/3 (I) | Window Shading, ft* (K) = (J) - (F) | % Shading, (K)/(G) = (L) | Shading Factor, (M) = 1 - (L) |
|---|---|---|---|---|---|
| S | | | | | |
| O | | | | 0 | 1.0 |
| N | 1.35 | 0.9 | 0 | 0 | 1.0 |
| D | 1.2 | 0.8 | 0 | | 1.0 |
| J | 1.35 | 0.9 | 0 | 0 | |
| F | 1.8 | 1.2 | 0 | 0 | 1.0 |
| M | 2.85 | 1.9 | 0.7 | 0.2 | 0.8 |
| A | | | | | |
| M | | | | | |
| J | | | | | |

Enter Column (M) in Column 2, Worksheet 5.

* If (J) - (F) is less than zero, enter zero in Column (K).

** If window (glazing) height varies, a reasonable average can be assumed.

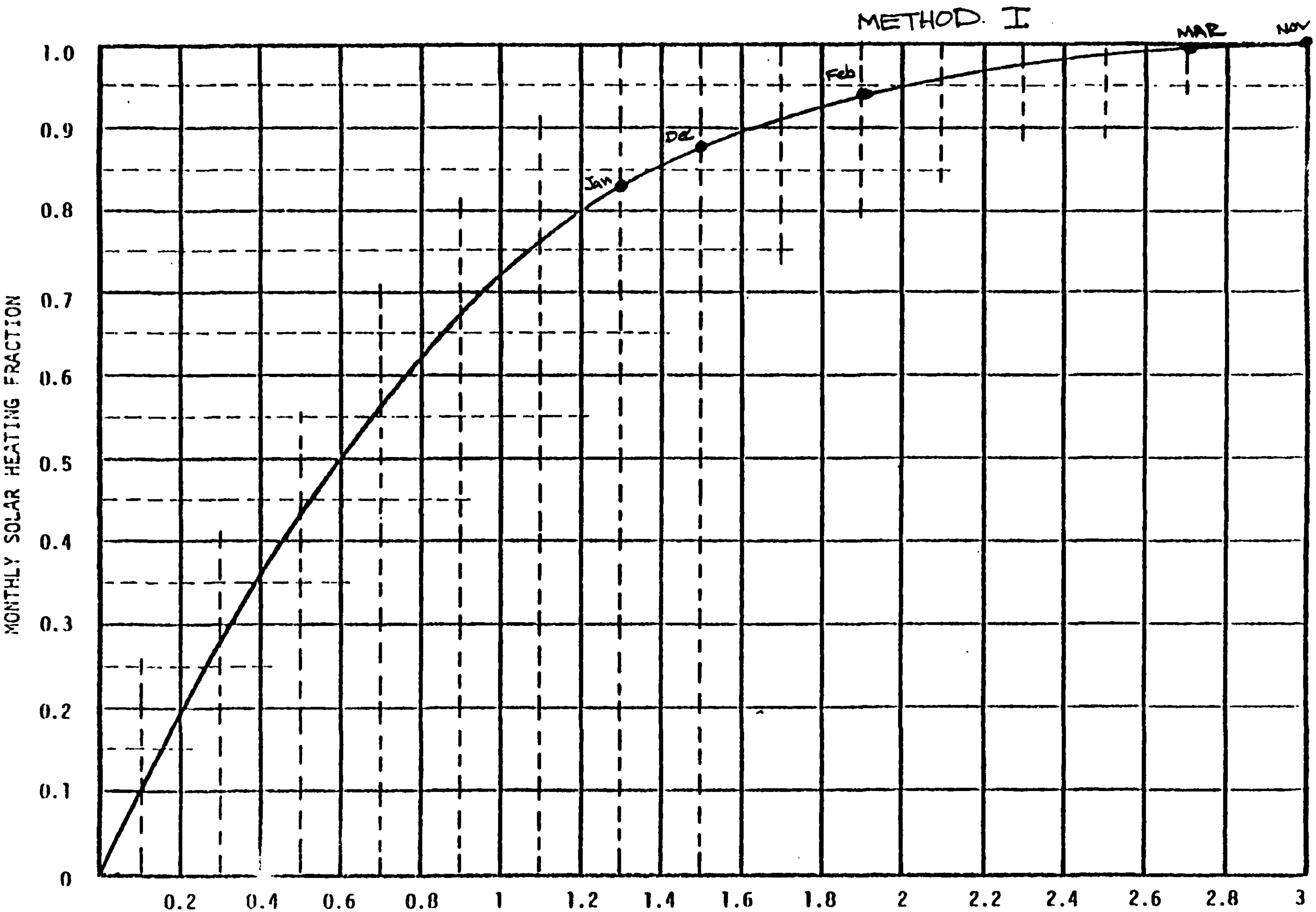
METHOD I

WORKSHEET 6

CALCULATION OF BUILDING AUXILIARY LOAD PROFILE

| Month | Net Thermal Load (from Worksheet 4) (A) | Total Solar Heat Gain (from Worksheet 5) (B) | Solar Load Ratio (SLR) (B) ÷ (A) (C) | Solar Heating Fraction (SHF) (from Fig. 5.7) (D) | Solar Heating Contrib. (D) x (A) (E) | Auxiliary Load Profile (A) - (E) (F) |
|---|---|---|---|---|---|---|
| Aug. | | | | | | |
| Sept. | | | | | | |
| Oct. | | | | | | |
| Nov. | 0.4 | 3.6* | >3 | 1.0 | 0.4 | 0 |
| Dec. | 2.5 | 3.9 | 1.56 | 0.89 | 2.2 | 0.3 |
| Jan. | 3.0 | 3.9 | 1.30 | 0.80 | 2.4 | 0.6 |
| Feb. | 2.0 | 3.7 | 1.85 | 0.93 | 1.9 | 0.1 |
| Mar. | 1.1 | 3.0* | 2.73 | 1.0 | 1.1 | 0 |
| Apr. | | | | | | |
| May | | | | | | |
| Jun. | | | | | | |
| Jul. | | | | | | |
| TOTAL | 9.0 MBtu | | | | 8.0 MBtu | 1.0 MBtu |

* INSTALL GLAZING AT ONSET OF COLD WEATHER; REMOVE BY MID-MARCH.




Monthly Passive Solar Heating Estimator

METHOD II WITH SEPARATE GREEN HOUSE CALCULATI[illegible]

METHOD II - HOUSE

WORKSHEET 1D

BUILDING DIMENSIONS
(for Worksheet 2)

CASA LEONA

| Orientation/ Type | Gross Wall Area, ft² | Window Area, ft² | Door Area, ft² | Net Wall Area, ft² | Perimeter ft |
|---|---|---|---|---|---|
| | ( ) - [( | )+( | )] = ( | ). | ( ) |
| Total NW | | | | | |
| Total N living | 32×9 = 288 | | - 80 | 208 | |
| Total N sleep | 28×8 = 224 | -19 | | 205 | |
| Total NE | | | | | |
| Total E | 32×10 = 320 | -26 | | 294 | |
| Total SE | | | | | |
| Total W | 32×10 = 320 | -10 | -20 | 290 | |
| Total SW | | | | | |
| Total S sleep. | 28 × 8.5 = 238 | -28 | | 210 | |
| Total S living | 32 × 9 = 288 | -9 | -60 | 219 | |
| Total Trombe | | | | | |
| Total Air Lock | | | | | |
| Total | ( 1678 ) - [( | 92 )+( | 160 )] = ( | 1426 ). | ( ) |

| Roof | Gross Roof Area | Skylights | Net Roof Area |
|---|---|---|---|
| | ( 1724 ) - | ( ) = | ( 1724 ) |

METHOD II - SUNPORCH

WORKSHEET 1D
BUILDING DIMENSIONS
(for Worksheet 2)

CASA LEONA

| Orientation/ Type | Gross Wall Area, $ft^2$ | Window Area, $ft^2$ | Door Area, $ft^2$ | Net Wall Area, $ft^2$ | Perimeter ft |
|---|---|---|---|---|---|
| | ( ) - [( | )+( | )] = ( | ). | ( ) |
| Total NW | | | | | |
| Total N | | | | | |
| Total NE | | | | | |
| Total E | 4 × 8.5 = 34 | - 12 | | 22 | |
| Total SE | | | | | |
| Total W | 6 × 8.5 = 51 | - 12 | | 39 | |
| Total SW | | | | | |
| Total S | 60 × 8 = 480 | - 172 | - 20 | 288 | |
| Total Trombe | | | | | |
| Total Air Lock | | | | | |
| Total | ( 565 ) - [( | 196 )+( | 20 )] = ( | 349 ). | ( ) |

| Roof | Gross Roof Area | Skylights | Net Roof Area |
|---|---|---|---|
| | ( 304 ) - | ( ) = | ( 304 ) |

METHOD II

METHOD II - HOUSE

WORKSHEET 2

CALCULATION OF BUILDING SKIN CONDUCTANCE

CASA LEONA

| Surface Type | Net Area $ft^2$ | | U-value Btu/hr-°F-$ft^2$ | | U x Area Btu/hr-°F* | % of Total |
|---|---|---|---|---|---|---|
| North exterior wall | 413 | X | | = | | |
| East exterior wall | 294 | X | | = | | |
| West exterior wall | 290 | X | 0.051 | = | | |
| South exterior wall | 429 | X | | = | | |
| South Trombe wall | | X | | = | | |
| Air lock walls | | X | | = | | |
| Total Wall Heat Loss | | | | | $\boxed{73}$ | 22% |
| Doors: Entry | | X | | = | | |
| Patio | 160 | X | 0.49 | = | 78 | |
| Other | | X | | = | | |
| North windows | 19 | X | | = | | |
| East windows | 26 | X | 0.35 | = | 32 | |
| West windows | 10 | X | | = | | |
| South windows | 37 | X | | = | | |
| Clerestory windows | | X | | = | | |
| Sloped skylights | | X | | = | | |
| Horizontal skylights | | X | | = | | |
| Total Door/Window Heat Loss | | | | | $\boxed{110}$ | 33% |
| Roof | 1724 | X | 0.039 | = | $\boxed{67}$ | 20% |
| Floor ** | 1664 | X | 0.05 | = | $\boxed{83}$ | 25% |
| Total Building Skin Conductance (add boxed-in values) | | | | | 333 | 100 |

* The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

** Crawlspace = $Ah_c$ (see Figure 4.1)

Slab = F x P (see Table 4.1)

Heated basement = $UA_{\text{wall above grade}} + h_b A_{\text{wall below grade}} + h_c A_{\text{floor}}$

METHOD II - SUNPORCH

WORKSHEET 2

CALCULATION OF BUILDING SKIN CONDUCTANCE

CASA LEONA

| Surface Type | Net Area $ft^2$ | | U-value $Btu/hr\text{-}°F\text{-}ft^2$ | | U x Area $Btu/hr\text{-}°F$* | % of Total |
|---|---|---|---|---|---|---|
| North exterior wall | | X | | = | | |
| East exterior wall | 22 | X | | = | | |
| West exterior wall | 39 | X | 0.09 | = | 32 | |
| South exterior wall | 288 | X | | = | | |
| South Trombe wall | | X | | = | | |
| Air lock walls | | X | | = | | |
| Total Wall Heat Loss | | | | | $\boxed{32}$ | |
| Doors: Entry | | X | | = | | |
| Patio | 20 | X | 0.5 | = | 10 | |
| Other | | X | | = | | |
| North windows | | X | | = | | |
| East windows | | X | | = | | |
| West windows | 196 | X | 1.13 | = | 221 | |
| South windows | | X | | = | | |
| Clerestory windows | | X | | = | | |
| Sloped skylights | | X | | = | | |
| Horizontal skylights | | X | | = | | |
| Total Door/Window Heat Loss | | | | | $\boxed{231}$ | |
| Roof | 304 | X | 0.039 | = | $\boxed{12}$ | |
| Floor ** | 304 | X | 0.05 | = | $\boxed{15}$ | |
| Total Building Skin Conductance (add boxed-in values) | | | | | 290 | 100 |

* The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

** Crawlspace = $Ah_c$ (see Figure 4.1)

Slab = F x P (see Table 4.1)

Heated basement = $UA_{\text{wall above grade}} + h_b A_{\text{wall below grade}} + h_c A_{\text{floor}}$

METHOD II-HOUSE

WORKSHEET 3

CALCULATION OF INFILTRATION LOAD AND
MODIFIED BUILDING HEAT LOSS COEFFICIENT $C_B$

CASA LEONA

House Volume = Gross Floor Area x Ceiling Height = ( 1664 ) ( 10 ) = 16,600

Infiltration Load = Volume x $C_p$ x ACH       ACH = Air Change/Hour

= (16,600) x (0.018) x (0.5)

= 150 Btu/hr-°F

Modified Building Heat Loss Coefficient, $C_B$

= [Building Skin Conductance* + Infiltration Load]

= 24 [( 150 ) + ( 333 )] = 24 ( 483 )

= 11,600 Btu/D.D.

Gross Heated Floor Area of Building = 1664 ft$^2$

$C_B$/A = ( 11,600 ) / ( 1664 )

= 7.0 Btu/ft$^2$-D.D.       D.D. = Degree Days**

* From Worksheet 2.

**"Degree Days" is an indication of the "coldness" of the climate for heating calculations; the degree-day value for a particular day is the difference between the average daily outdoor temperature and 65°F; the data is usually given in monthly and yearly totals. Averaged degree-day data for New Mexico is listed in Table 1-1.

METHOD II - SUNPORCH

WORKSHEET 3

CALCULATION OF INFILTRATION LOAD AND
MODIFIED BUILDING HEAT LOSS COEFFICIENT $C_B$

CASA LEONA

House Volume = Gross Floor Area x Ceiling Height = ( 304 )( 8 ) = 2430
Infiltration Load = Volume x $C_p$ x ACH          ACH = Air Change/Hour
= (2430) x (0.018) x ( 1.0 )
= 44 Btu/hr-°F

Modified Building Heat Loss Coefficient, $C_B$

= [Building Skin Conductance* + Infiltration Load]

= 24 [( 290 ) + ( 44 )] = 24 ( 334 )

= 8016 Btu/D.D.

Gross Heated Floor Area of Building = 304 $ft^2$

$C_B$/A = ( 8016 ) / ( 304 )
= 26.3 Btu/$ft^2$-D.D.          D.D. = Degree Days**

* From Worksheet 2.

**"Degree Days" is an indication of the "coldness" of the climate for heating calculations; the degree-day value for a particular day is the difference between the average daily outdoor temperature and 65°F; the data is usually given in monthly and yearly totals. Averaged degree-day data for New Mexico is listed in Table 1-1.

METHOD II - HOUSE

WORKSHEET 4

CALCULATION OF BUILDING THERMAL LOAD PROFILE CASA LEONA.

Modified Building Heat Loss Coefficient $C_B$ from Worksheet 3 = 11600 Btu/D.D.

| Month | Degree Days per Month | x $C_B$ | = | Gross Thermal Load, MBtu/month | - | Internal Heat Sources, MBtu/month | = | Net Thermal Load, MBtu/month |
|---|---|---|---|---|---|---|---|---|
| Aug. | ____ | x $C_B$ | = | ____ | - | ____ | = | ____ |
| Sept. | ____ | x $C_B$ | = | ____ | - | ____ | = | ____ |
| Oct. | | | | | | | | |
| Nov. | 80 | | | .93 | | 1 | | 0 |
| Dec. | 200 | | | 2.3 | | 1 | | 1.3 |
| Jan. | 230 | | | 2.7 | | 1 | | 1.7 |
| Feb. | 170 | | | 2.0 | | 1 | | 1.0 |
| Mar. | 120 | | | 1.4 | | 1 | | 0.4 |
| Apr. | | | | | | | | |
| May | | | | | | | | |
| Jun. | | | | | | | | |
| Jul. | | | | | | | | |
| MBtu = Million Btu | | | | | | | | 4.4 |

METHOD II - SUNPORCH

WORKSHEET 4

CALCULATION OF BUILDING THERMAL LOAD PROFILE CASA LEONA

Modified Building Heat Loss Coefficient $C_B$ from Worksheet 3 = 8000 Btu/D.D.

| Month | Degree Days per Month | x $C_B$ | = | Gross Thermal Load, MBtu/month | – | Internal Heat Sources, MBtu/month | = | Net Thermal Load, MBtu/month |
|---|---|---|---|---|---|---|---|---|
| Aug. | ____ | x $C_B$ | = | ____ | – | ____ | = | ____ |
| Sept. | ____ | x $C_B$ | = | ____ | – | ____ | = | ____ |
| Oct. | | | | | | | | |
| Nov. | 80 | | | 0.6 | | | | 0.6 |
| Dec. | 200 | | | 1.6 | | | | 1.6 |
| Jan. | 230 | | | 1.8 | | | | 1.8 |
| Feb. | 170 | | | 1.4 | | | | 1.4 |
| Mar. | 120 | | | 1.0 | | | | 1.0 |
| Apr. | | | | | | | | |
| May | | | | | | | | |
| Jun. | | | | | | | | |
| Jul. | | | | | | | | |
| MBtu = Million Btu | | | | | | | | 6.4 |

METHOD II

WORKSHEET 5 IS AS IN METHOD I

WORKSHEET 5A

ADJUSTED NET SOLAR GREENHOUSE HEAT GAIN

CASA LEONA

| Month | Solar Heat Gain Absorbed (from Worksheet 5 of Greenhouse Calculations) | - | Monthly Heat Loss (Net Thermal Load) from Worksheet 4* MBtu/month | = | Net Heat Gain MBtu/month x Adjustment Factor ( 0.6 ) | = | Adjusted Net Solar Greenhouse Heat Gain |
|---|---|---|---|---|---|---|---|
| Aug. | | | | | | | |
| Sept. | | | | | | | |
| Oct. | | | | | | | |
| Nov. | 3.6 | | 0.6 | | 3.0 | | 1.8 |
| Dec. | 3.9 | | 1.6 | | 2.3 | | 1.4 |
| Jan. | 3.9 | | 1.8 | | 2.1 | | 1.3 |
| Feb. | 3.7 | | 1.6 | | 2.3 | | 1.4 |
| Mar. | 3.0 | | 1.0 | | 2.0 | | 1.2 |
| Apr. | | | | | | | |
| May | | | | | | | |
| Jun. | | | | | | | |
| Jul. | | | | | | | |

*For greenhouse heat loss to the outside only.

METHOD II

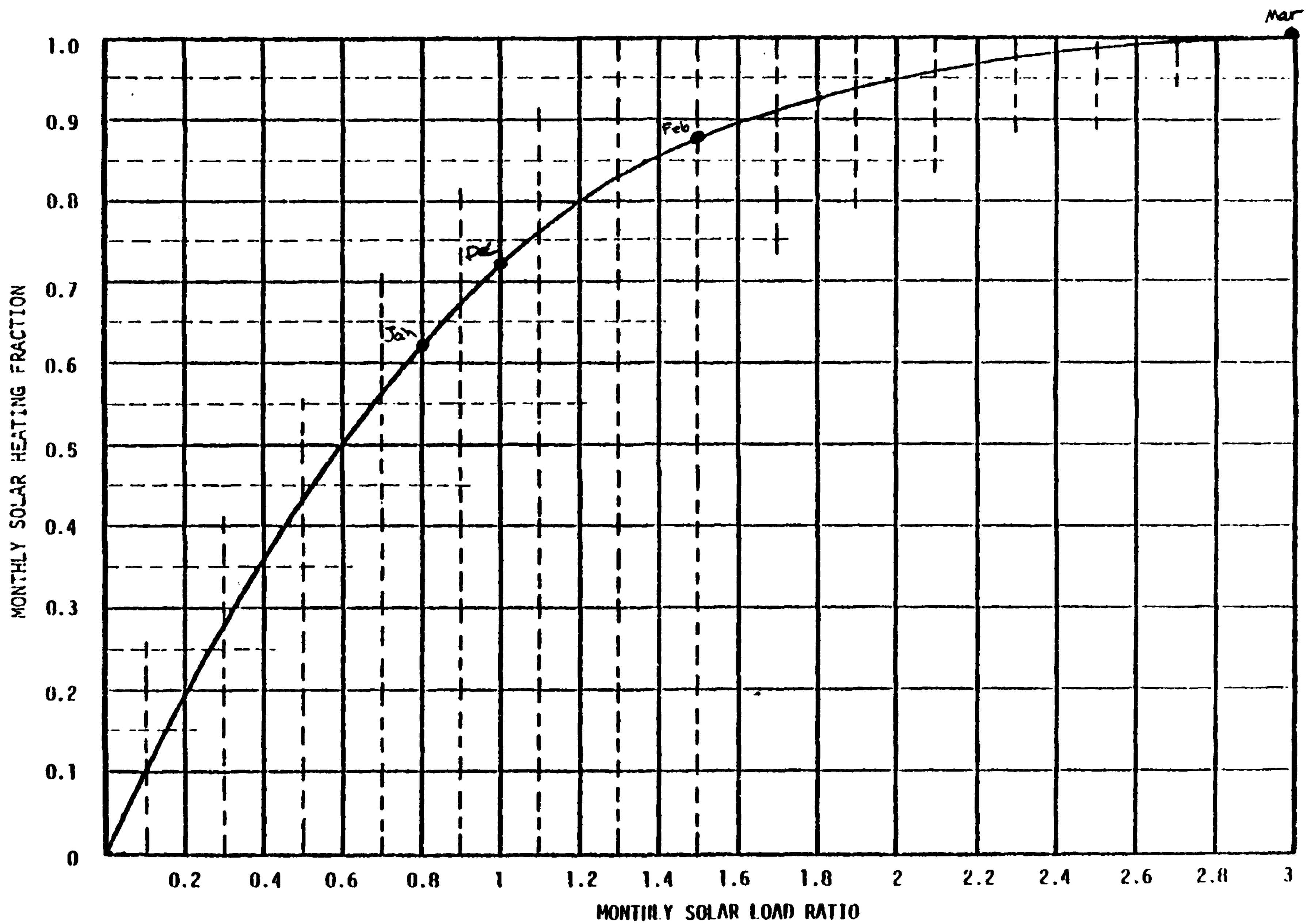
WORKSHEET 6

CALCULATION OF BUILDING AUXILIARY LOAD PROFILE CASA LEONA.

| Month | Net Thermal Load (from Worksheet 4) (A) | Total Solar Heat Gain (from Worksheet 5) (B) | Solar Load Ratio (SLR) (B) ÷ (A) (C) | Solar Heating Fraction (SHF) (from Fig. 5.7) (D) | Solar Heating Contrib. (D) x (A) (E) | Auxiliary Load Profile (A) - (E) (F) |
|---|---|---|---|---|---|---|
| Aug. | | | | | | |
| Sept. | | | | | | |
| Oct. | | | | | | |
| Nov. | — | 1.8 | — | — | — | — |
| Dec. | 1.3 | 1.4 | 1.08 | .75 | 1 | 0.3 |
| Jan. | 1.6 | 1.3 | 0.81 | .62 | 1.0 | 0.6 |
| Feb. | 0.9 | 1.4 | 1.56 | .89 | 0.8 | 0.1 |
| Mar. | 0.4 | 1.2 | 73 | 1.0 | 0.4 | 0 |
| Apr. | | | | | | |
| May | | | | | | |
| Jun. | | | | | | |
| Jul. | | | | | | |
| TOTAL | 4.2 MBtu | | | | 3.2 MBtu | 1.0 MBtu |

NOTE THAT NO SPECIFIC NET STORAGE MASS HAS BEEN INCORPORATED INTO THIS DESIGN. IF TEMPERATURES FLUCTUATE TOO WILDLY, SOME WATER STORAGE OR PHASE CHANGE MATERIALS MAY BE RETROFITTED INTO THE SUN PORCH FOR WINTER USE.

METHOD II



Monthly Passive Solar Heating Estimator

## Discussion of Results

For designs that incorporate a sunspace/greenhouse, there are two methods of calculating the auxiliary heat load. These alternate procedures are illustrated with this design example. Method 1 considers the house and attached sunspace as one unit, with the sunporch representing the S exterior wall of the building in the heat loss calculations. This method is especially appropriate when the sunspace is well-integrated with the building, when heat transfer into the house is made easily, and when the sunspace glazing can be insulated at night, especially in cooler climates. Method 2 first considers the heat loss of the house by itself, taking as the S wall the common wall between sunspace and dwelling. The presence of the sunspace serves to reduce infiltration and is thus taken into account when choosing a value for ACH. One advantage of this method is that the resulting modified building heat loss coefficient $C_B/A$ can more realistically be compared with the values recommended in Table 4.7. A separate heat loss calculation is made for the greenhouse/sunspace (ignoring the common wall between sunspace and house, since no heat loss is expected to occur in that direction on a completely cloudy day). As seen in the example, the $C_B/A$ of Method 1 was calculated to be 8.9 Btu/ft$^2$-D.D. for the combined structure; Method 2 gave 6.85 Btu/ft$^2$-D.D. for the house alone and 26 Btu/ft$^2$-D.D. for the sunporch.

The building is assumed to be sited 20°E of S to better catch prevailing summer breezes. The main design objective was to reduce summer cooling loads. As far as passive solar heating is concerned, the design could be called sun-tempered rather than completely passive, because no thermal mass has been incorporated for heat storage. Over 1/3 of the gross heat load is being met by the internal heat sources. As soon as weather turns cool in November, the sunporch glazing can be installed; it can be partially or completely removed in March with the onset of warmer weather. In the winter, the sunporch will be ideal for plants. In the summer most plants should be moved to the N porch or into the garden to avoid adding humidity to the house. The auxiliary heat load calculated with both methods is a total of 1 MBtu for an average heating season. This is a very small load which can be supplied with individual heaters (electric or gas). The master bedroom will be the coolest in the winter since it has no direct access to solar heat.

The specific features which reduce the summer cooling load are:

(1) Vented crawlspace
(2) Carport on W side (shaded with roof and/or trees)
(3) Shaded porches on N, S
(4) Central breezeway in house
(5) Breezeway between carport storage and house
(6) Central hall and windows for cross-ventilation if summer breeze turns 90° to NE or SW
(7) Laundry room in air lock downwind of prevailing summer breeze
(8) Exhaust fans in bathrooms which are not downwind of breeze
(9) Sloped, high ceiling with vents to hall in BR wing; exhaust fan from each wing to attic
(10) Transoms over bedroom doors for increased natural ventilation (and to preserve privacy)
(11) Main water heater isolated from living space
(12) Tall trees, with minimum undergrowth are recommended for the SE and SW corner and other places in front of the house (where they can shade the roof in the summer yet allow the lower winter sun through the sunporch glazing). The driveway must be shaded with trees in the summer also as well as the N, E and W walls of the house. Lawns should extend up to the house (no shrubs).
(13) Attic vents (gable ends) and attic fan (monitor)
(14) Double-hung windows to allow low or high air intake. Optionally, E and W windows may be casements opening toward the S to catch the breeze
(15) Light-colored wood parquet flooring in living/dining room for cool summer feeling
(16) Awnings on E-W windows if not shaded by trees
(17) Natural lighting in all rooms and halls.

For additional energy conservation, two solar water heaters can be incorporated into the design. The backup thermostat in the bathroom water heater may be set quite low (90° - 100°F), the one near the kitchen up to 140°F (if a dishwasher is used). For very southern latitudes, the collector panels can be installed on the lower part of the roof, with the tank high in the attic space for thermo-syphon operation. The collector panels must be located where they will not receive any shading from trees year-round.

## ATTACHMENT

## SET OF WORKSHEET BLANKS FOR XEROXING

A set of loose-leaf worksheets is provided here for making xerox copies; the design of a passive house from the initial concept to final drawings usually requires at least three sets.

WORKSHEET 1A

DESIGN INFORMATION

1. Location of building: ________ Altitude: ________
2. Building type (one or two story, split-level, etc.): ________
3. Roof shape: ________
4. Lot size: ________ Special features: ________
5. Lot orientation (in which direction will the house face the street?): ____
6. Building setbacks (check with local codes): ________
7. Zoning restrictions and covenants: ________
8. Lot access: ________
9. Utility access: ________
10. Lot slope, water runoff (erosion?), berming: ________
11. Predominant direction of winter wind: ____ Velocity: ____ mph average
12. Predominant direction of summer breeze: ____ Velocity: ____ mph average
13. Direction of best view: ________
14. Direction of worst view: ________
15. Shading from neighboring houses, trees, etc.: ________
16. Approximate floor area: ________ Heated basement? ________
17. Number of occupants: ________
18. Number of bedrooms, baths: ________
19. Other living spaces wanted: ________
20. Life style of occupants and special needs (i.e. play area for children, space for entertaining, hobbies; space used during day, evening; special storage requirements; handicaps): ________
21. Preferred patio location, other outdoor recreation areas: ________
22. Occupants like the following features: ________
23. Occupants dislike the following features: ________

WORKSHEET 1B

SPACE RELATIONSHP DIAGRAM

Floor area: ______________ sq. ft.

Sketch the location of the main entry and the living, cooking, eating and sleeping areas; then mark the major wind directions and place kitchen, baths, utility, and laundry rooms downwind of the prevailing summer breeze. Use storage areas and garage/carport as buffer zones against winter winds and summer heat. Indicate the zoning barrier (■ ■ ■) and tentatively mark the location of auxiliary wood burners (✳) (if any). Areas thus marked will need to be designed so that they can be completed closed off from the remaining sections of the house during periods when auxiliary heating is necessary. Finally, show the direction(s) of the best view (and, optionally, undersirable views which will need to be screened). Indicate roof overhangs, porches and other means of shading, especially for E and W walls.

## WORKSHEET 1C

## ADDITIONAL INFORMATION AND CHECKLIST FOR ENERGY CONSERVATION

| | |
|---|---|
| | Building orientation is primarily broadside to prevailing summer breeze |
| | Windbreaks are provided against winter storms. |
| | Windows are of double-glazed casement or double-hung type? ________ |
| | Window areas to the north, east and west are minimized. |
| | E and W walls are completely shaded in the summer. |
| | Windows allow sufficient natural summer ventilation. |
| | Windows are insulated at night by (insulated drapes, shades, louvers, interior or exterior shutters): ________________ |
| | Can such shutters be used as hurricane protection if necessary? ___ |
| | Passive solar mechanisms included in the design are: ________ ________________________________ |
| | Storage mass is located at: ________________ ________________________________ |
| | Are fans used for heat distribution or cooling?: _____ Where? ___ ________________________________ |
| | Is there a solar greenhouse? ________________ |
| | Will plants in the house be away from direct sun? ________ |
| | Can humidity in the house be easily vented? ________ |
| | Is the main entry an air lock in the winter? ________ |
| | What type backup space heater is planned? ________ |
| | Will a solar water heater be used? _____ What type? ________ |
| | Solar tank location, size: ________________ ________________________________ |
| | Collector location: ________ Type: ________ Area needed: _____ |
| | Heat exchanger(s): ________________ |
| | Collector slope (approximately equal to latitude +10° is best): ___ |
| | Backup water heater, type, size, fuel: ________________ |
| | Is the water heater isolated from the living space? ________ |
| | Energy-efficient applicances to be used are: ________ ________________________________ |
| | Fluorescent lights are to be used in: ________________ ________________________________ |
| | Wood burner or stove? ________ Output: ________ Btu/hr |

WORKSHEET 1D

BUILDING DIMENSIONS
(for Worksheet 2)

| Orientation/ Type | Gross Wall Area, ft$^2$ | Window Area, ft$^2$ | Door | Net Wall Area, ft$^2$ | Perimeter ft |
|---|---|---|---|---|---|
| | (      ) - [( | )+( | )] = ( | ). | (      ) |
| Total NW<br>Total N<br>Total NE<br>Total E<br>Total SE<br>Total W<br>Total SW<br>Total S<br>Total Trombe<br>Total Air Lock | | | | | |
| Total | (      ) - [( | )+( | )] = ( | ). | (      ) |
| Roof | Gross Roof Area (      ) - | Skylights (      ) = | Net Roof Area (      ) | | |

WORKSHEET 2

CALCULATION OF BUILDING SKIN CONDUCTANCE

| Surface Type | Area $ft^2$ | | U-value Btu/hr-°F-$ft^2$ | | U x Area Btu/hr-°F** | % of Total |
|---|---|---|---|---|---|---|
| North exterior wall | ____ | X | ____ | = | ____ | |
| East exterior wall | ____ | X | ____ | = | ____ | |
| West exterior wall | ____ | X | ____ | = | ____ | |
| South exterior wall | ____ | X | ____ | = | ____ | |
| South Trombe wall | ____ | X | ____ | = | ____ | |
| Air lock wall | ____ | X | ____ | = | ____ | |
| Total Wall Heat Loss | | | | | $\boxed{\phantom{000}}$ | ____ |
| Doors: Entry | ____ | X | ____ | = | ____ | |
| Patio | ____ | X | ____ | = | ____ | |
| ____ | ____ | X | ____ | = | ____ | |
| North windows | ____ | X | ____ | = | ____ | |
| East windows | ____ | X | ____ | = | ____ | |
| West windows | ____ | X | ____ | = | ____ | |
| South windows | ____ | X | ____ | = | ____ | |
| Clerestory windows | ____ | X | ____ | = | ____ | |
| Sloped skylights | ____ | X | ____ | = | ____ | |
| Horizontal skylights | ____ | X | ____ | = | ____ | |
| Total Door/Window Heat Loss | | | | | $\boxed{\phantom{000}}$ | ____ |
| Roof | ____ | X | ____ | = | $\boxed{\phantom{000}}$ | ____ |
| Slab Edge = F X P* | ____ | X | ____ | = | $\boxed{\phantom{000}}$ | ____ |
| Total Building Skin Conductance (add boxed-in values) | | | | | ____ | 100 |

*See Table 7-2.

**The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

## WORKSHEET 2

## CALCULATION OF BUILDING SKIN CONDUCTANCE

| Surface Type | Area $ft^2$ | | U-value Btu/hr-°F-$ft^2$ | | U x Area Btu/hr-°F** | % of Total |
|---|---|---|---|---|---|---|
| North exterior wall | ______ | X | ______ | = | ______ | |
| East exterior wall | ______ | X | ______ | = | ______ | |
| West exterior wall | ______ | X | ______ | = | ______ | |
| South exterior wall | ______ | X | ______ | = | ______ | |
| South Trombe wall | ______ | X | ______ | = | ______ | |
| Air lock wall | ______ | X | ______ | = | ______ | |
| Total Wall Heat Loss | | | | | $\boxed{\phantom{000}}$ | ______ |
| Doors: Entry | ______ | X | ______ | = | ______ | |
| Patio | ______ | X | ______ | = | ______ | |
| ______ | ______ | X | ______ | = | ______ | |
| North windows | ______ | X | ______ | = | ______ | |
| East windows | ______ | X | ______ | = | ______ | |
| West windows | ______ | X | ______ | = | ______ | |
| South windows | ______ | X | ______ | = | ______ | |
| Clerestory windows | ______ | X | ______ | = | ______ | |
| Sloped skylights | ______ | X | ______ | = | ______ | |
| Horizontal skylights | ______ | X | ______ | = | ______ | |
| Total Door/Window Heat Loss | | | | | $\boxed{\phantom{000}}$ | ______ |
| Roof | ______ | X | ______ | = | $\boxed{\phantom{000}}$ | ______ |
| Slab Edge = F X P* | ______ | X | ______ | = | $\boxed{\phantom{000}}$ | ______ |
| Total Building Skin Conductance (add boxed-in values) | | | | | ______ | 100 |

*See Table 7-2.

**The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

WORKSHEET 3

CALCULATION OF INFILTRATION LOAD AND
MODIFIED BUILDING HEAT LOSS COEFFICIENT $C_B$

House Volume = Gross Floor Area x Ceiling Height =(      )(      )=____

Infiltration Load = Volume x $C_p$ x ACH    ACH = Air Change/Hour

= (      ) x (      ) x (      )

= ________ Btu/hr-°F

Modified Building Heat Loss Coefficient, $C_B$

= [Building Skin Conductance* + Infiltration Load]

= 24 [(      ) + (      )] = 24 (      )

= ____________________ Btu/D.D.

Gross Heated Floor Area of Building = ________ $ft^2$

$C_B$/A = (      ) / (      )

= ____________ Btu/$ft^2$-D.D.    D.D. = Degree Days**

* From Worksheet 2.

**"Degree Days" is an indication of the "coldness" of the climate for heating calculations; the degree-day value for a particular day is the difference between the average daily outdoor temperature and 65°F; the data is usually given in monthly and yearly totals.

## WORKSHEET 4

### CALCULATION OF BUILDING THERMAL LOAD PROFILE

Modified Building Heat Loss Coefficient $C_B$ from Worksheet 3 = _____ Btu/D.D.

| Month | Degree Days per Month | x $C_B$ | = | Gross Thermal Load, MBtu/month | – | Internal Heat Sources, MBtu/month | = | Net Thermal Load, MBtu/month |
|---|---|---|---|---|---|---|---|---|
| Aug. | _____ | x $C_B$ | = | _____ | – | _____ | = | _____ |
| Sept. | _____ | x $C_B$ | = | _____ | – | _____ | = | _____ |
| Oct. | | | | | | | | |
| Nov. | | | | | | | | |
| Dec. | | | | | | | | |
| Jan. | | | | | | | | |
| Feb. | | | | | | | | |
| Mar. | | | | | | | | |
| Apr. | | | | | | | | |
| May | | | | | | | | |
| Jun. | | | | | | | | |
| Jul. | | | | | | | | |

MBtu = Million Btu

## WORKSHEET 5
## CALCULATION OF SOLAR HEATING CONTRIBUTION

Mechanism: ______________________________

Net Effective Collector Area: ____________ ft$^2$ = $A_{eff}$

$A_{eff} = A_{gross}$ x (Frame Shading) x (Effectiveness, Table 5.1)

| Month | Solar Heat Gain from Figures 5.2 & 5.3 Btu/Month-ft$^2$ x $10^3$ (1) | Adjustment Factors: Roof Overhang from Worksheet 5B (2) | Adjustment Factors: Off South Orientation: % Reduction from Sec. 5.3 (3) | Solar Heat Absorbed in MBtu/month $A_{eff}$ x (1) x (2) x (3) |
|---|---|---|---|---|
| Aug. | | | | |
| Sept | | | | |
| Oct. | | | | |
| Nov. | | | | |
| Dec. | | | | |
| Jan. | | | | |
| Feb. | | | | |
| Mar. | | | | |
| Apr. | | | | |
| May | | | | |
| Jun. | | | | |
| Jul. | | | | |

WORKSHEET 5A

ADJUSTED NET SOLAR GREENHOUSE HEAT GAIN

| Month | Solar Heat Gain Absorbed (from Worksheet 5 of Greenhouse Calculations) | | Monthly Heat Loss (Net Thermal Load) from Worksheet 4* MBtu/month | | Net Heat Gain MBtu/month x Adjustment Factor (      ) | = | Adjusted Net Solar Greenhouse Heat Gain |
|---|---|---|---|---|---|---|---|
| Aug. | __________ | − | __________ | = | __________ | | __________ |
| Sept. | | | | | | | |
| Oct. | | | | | | | |
| Nov. | | | | | | | |
| Dec. | | | | | | | |
| Jan. | | | | | | | |
| Feb. | | | | | | | |
| Mar. | | | | | | | |
| Apr. | | | | | | | |
| May | | | | | | | |
| Jun. | | | | | | | |
| Jul. | | | | | | | |

*For greenhouse heat loss to the outside only.

WORKSHEET 5B

CALCULATION OF SHADING WITH SOUTH ROOF OVERHANG

(A) Latitude of building site: _____ °N

(B) Length of summer shadow desired: _______ ft

(C) Size of roof overhang (projection from south wall)
from Table 5.2 (directly or interpolated): ___________ ft

(D) Height of lower overhang edge from finished floor: ____________ ft

(E) Distance from finished floor to top of glazing: __________ ft

(F) Vertical distance from top of glazing to roof overhang:
(D) - (E) = ___________ ft

(G) Window or glazing height: _________ ft**

| Month | Height of Shadow Cast, ft (H) x (C) = (I) | Effective Shadow Length, ft (J) = 2/3 (I) | Window Shading, ft* (K) = (J) - (F) | % Shading, (K)/(G) = (L) | Shading Factor, (M) = 1 - (L) |
|---|---|---|---|---|---|
| S | | | | | |
| O | | | | | |
| N | | | | | |
| D | | | | | |
| J | | | | | |
| F | | | | | |
| M | | | | | |
| A | | | | | |
| M | | | | | |
| J | | | | | |

Enter Column (M) in Column 2, Worksheet 5.

* If (J) - (F) is less than zero, enter zero in Column (K).

** If window (glazing) height varies, a reasonable average can be assumed.

WORKSHEET 6

CALCULATION OF BUILDING AUXILIARY LOAD PROFILE

| Month | Net Thermal Load (from Worksheet 4) (A) | Total Solar Heat Gain (from Worksheet 5) (B) | Solar Load Ratio (SLR) (B) ÷ (A) (C) | Solar Heating Fraction (SHF) (from Fig. 5.6) (D) | Solar Heating Contrib. (D) x (A) (E) | Auxiliary Load Profile (A) - (E) (F) |
|---|---|---|---|---|---|---|
| Aug. | | | | | | |
| Sept. | | | | | | |
| Oct. | | | | | | |
| Nov. | | | | | | |
| Dec. | | | | | | |
| Jan. | | | | | | |
| Feb. | | | | | | |
| Mar. | | | | | | |
| Apr. | | | | | | |
| May | | | | | | |
| Jun. | | | | | | |
| Jul. | | | | | | |
| TOTAL | MBtu | | | | MBtu | MBtu |

WORKSHEET 7

GLAZING AND STORAGE CALCULATIONS

Daily Maximum Solar Heat Gain:________

| Room | South Glazing $ft^2$ | Floor Area $ft^2$ | Designed Storage $ft^3$ | Storage Volume per 100 $ft^2$ of Glazing $ft^3$ | Temp. Swing °F |
|---|---|---|---|---|---|
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| ..... | | | | | |
| | ____ | ____ | ____ | ____ | |
| TOTAL | ==== | ==== | ==== | ==== | |

Check for temperature drop during a completely cloudy day (24-hour period):

$$\text{Maximum } \Delta T = \frac{\text{Net January Thermal Load*}/31}{\text{Total Volume x (Heat Capacity of Storage Material)**}}$$

$$\Delta T = \frac{(\qquad)}{31\,(\qquad)\,(\qquad\qquad)} = \_\_\_\_\_\_\_\_ {}^\circ F$$

*From Worksheet 4.
**From Table 6.1.

WORKSHEET 8A

CALCULATIONS FOR REFERENCE BUILDING

Building Location: Zone:

Floor Area:_____ $ft^2$ = (_____ft)$^2$; Perimeter = _____ft;

S. Window Area = (0.1)(A)÷4 = _______$ft^2$;

Effective Area = ½( )( )( ) = _____$ft^2$

Building Skin Conductance (Btu/hr-°F):

Total Wall and Window Combination: U-Value x Area = ( )x( )=_____

Roof: U-Value x Area = ( )x( )=_____

Floor (R=_____): F x Perimeter: (see Table 7-2) = ( )x( )=_____

TOTAL $\boxed{\quad}$

Infiltration: Volume x $C_p$ x ACH = ( ) x ( ) x 1 = $\boxed{\quad}$

Modified Building Heat Loss Coefficient $C_B$

= 24 (Skin Conductance + Infiltration) = 24[( + )] = $\boxed{\quad}$

$C_B/A$ = $\boxed{\quad}$ Btu/D.D.-$ft^2$

Heat Load Calculations(MBtu): Gross Heating Load minus Solar Heat Absorbed is equal to Net Heating Load

| Month | Degree Days | Gross Heating Load | Solar Gain | Solar Heat Absorbed | Net Heating Load |
|---|---|---|---|---|---|
| Aug. | | | | | |
| Sept. | | | | | |
| Oct. | | | | | |
| Nov. | | | | | |
| Dec. | | | | | |
| Jan. | | | | | |
| Feb. | | | | | |
| Mar. | | | | | |
| Apr. | | | | | |
| May | | | | | |
| Jun. | | | | | |
| Jul. | | | | | |

WORKSHEET 8B

HEAT SAVINGS CALCULATIONS FOR PASSIVE DESIGN*

| Month | Reference Bldg. Heating Load | Passive Solar Building Aux. Load | Gross Heat Saved | Parasitic Power (See Footnote), kWh x 0.0034 | Net Energy Saved | Cost of Energy Saved: ELECTRICITY: cents/kWh x 2.93 GAS: $/MCF x 1.7 ** OIL: $/gal x 14.4 *** WOOD: $/cord x 0.11 **** = ____ $/MBtu x Net Savings = | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MBtu/mo. | MBtu/mo. | MBtu | MBtu | MBtu | $ | | | |
| | | | | | | EL | GAS | OIL | WOOD |
| Aug. | (   ) - | (   ) = | | | | | | | |
| Sept. | | | | | | | | | |
| Oct. | | | | | | | | | |
| Nov. | | | | | | | | | |
| Dec. | | | | | | | | | |
| Jan. | | | | | | | | | |
| Feb. | | | | | | | | | |
| Mar. | | | | | | | | | |
| Apr. | | | | | | | | | |
| May | | | | | | | | | |
| Jun. | | | | | | | | | |
| Jul. | | | | | | | | | |
| TOTAL | | | | | | | | | |

*Does not include savings for solar water heating (or summer cooling).

**60% efficiency.

*** 1 MBtu = 7.2 gal. heating oil, 50% efficiency.

****Average of 20 MBtu per cord of wood depending on type [15] and 45% efficiency.

Add electricity needed to run the conventional furnace; substract the electricity needed to operate fans in the passive design.

DATE
FILMED

8